IPCC WGII Fourth Assessment Report – Draft for Government and Expert Review

Chapter 7 – Industry, Settlement, and Society

Coordinating Lead Authors
Tom Wilbanks (USA), Patricia Romero-Lankao (Mexico)

Lead Authors
Manzhu Bao (China), Frans Berkhout (Netherlands), Sandy Cairncross (UK), Jean-Paul Ceron (France), Manmohan Kapshe (India), Robert Muir-Wood (UK), Ricardo Zapata-Marti (ECLAC / Mexico)

Contributing Authors
M. Agnew (UK), R. Black (UK), T. Downing (UK), S. Gossling (Sweden), M-C. Lemos (Brazil), K. O'Brien (Norway), C. Pfister (Switzerland), W. Solecki (USA), C. Vogel (South Africa)

Review Editors
Edmundo de Alba Alcarez (Mexico), David Satterthwaite (UK), Y. Dhammika Wanasinghe (Sri Lanka)

Contents

Executive Summary

Virtually all of the world's people live in settlements, and many depend on industry, services, and infrastructures for jobs, well-being, and mobility. For them, climate change adds a new challenge in assuring sustainable development for societies across the globe. Impacts associated with this challenge will be determined mainly by <u>trends in human systems</u> in coming decades as climate conditions exacerbate or ameliorate stresses associated with these other systems

Inherent uncertainties in predicting the path of technological and institutional change and trends in socioeconomic development over a period of many decades limit the potential to predict future prospects for industry, settlements, and society involving *considerable* climate change from prospects involving *relatively little* climate change. In many cases, therefore, research to date has tended to focus on <u>vulnerabilities to impacts</u> rather than on <u>projections of impacts</u> of change.

Key vulnerabilities of industry, settlement, and society are most often related to (a) climate phenomena that exceed thresholds for adaptation, related to the rate and magnitude of climate change, particularly extreme weather events and/or abrupt climate change, and (b) limited access to resources (financial, human, institutional) to cope, rooted in issues of development context.

The main findings are of two types:

The Context for Assessing Vulnerabilities:

For industry, settlements, and society:

- Climate change vulnerabilities are mainly to extreme weather events rather than to gradual climate change. The significance of gradual climate change, e.g., increases in the mean temperature, lies mainly in related changes in the intensity and frequency of extreme events. VERY HIGH CONFIDENCE (7.2, 7.4)
- Aside from major extreme events, climate change is often a secondary factor in considering stresses on sustainability. Its significance (positive or negative) lies in its interactions with <u>other</u> sources of change and stress, and its impacts should be considered in such a multi-cause context. VERY HIGH CONFIDENCE (7.1.3, 7.2, 7.4)
- Vulnerabilities to climate change depend considerably on relatively specific geographic and sectoral contexts. As a result, they are not reliably estimated by large-scale (aggregate) modeling and estimation. VERY HIGH CONFIDENCE (7. 2, 7.4)
- Climate change impacts spread from directly impacted areas and sectors to other areas and sectors through extensive and complex linkages. In many cases, total impacts are poorly estimated by considering only direct impacts. VERY HIGH CONFIDENCE (7.4)

Conclusions about vulnerabilities:

- Vulnerabilities of industry, infrastructures, settlements, and society are greater in certain high-risk locations, particularly coastal and riverine areas subject to flooding and areas whose economies are closely linked with climate-sensitive resources, such as agro-processing, water resources, and tourism. VERY HIGH CONFIDENCE (7.4, 7.5)
- Because a substantial share of projected population growth is likely to be in areas vulnerable to impacts of climate change, potential effects of climate change on settlements and populations are likely to increase through time. HIGH CONFIDENCE (7.3, 7.4.3)
- Expressed in terms of annual regional gross domestic product and/or capital formation, costs of extreme weather events -- which are likely to become more intense and/or more frequent with climate change, -- can range from several percent in larger, more developed and

diversified impacted regions to more than twenty-five percent in smaller less developed, less diversified, and/or more natural resource dependent regions. At a local scale, however, such events can be catastrophic, with much higher levels of costs, at least in the short run. VERY HIGH CONFIDENCE (7.5)

- In most parts of the world and most segments of populations, lifestyles will change as a result of climate change. Net valuations of benefits vs. costs will vary, but they are more likely to be negative if climate change is substantial and rapid rather than if it is moderate and gradual. VERY HIGH CONFIDENCE (7.4, 7.6)
- Poor communities and households are especially vulnerable to climate change because they tend to be located in relatively high-risk areas and to have limited access to services and other resources for coping. They are likely to be impacted at lower levels and rates of climate change than the relatively wealthy. MEDIUM CONFIDENCE (7.4.5, 7.4.6)
- With increased catastrophe loss costs, the private insurance sector is likely to increase prices and withdraw coverage from situations at highest risk, leaving an increased role for governments and individuals as risk bearers. HIGH CONFIDENCE (7.4.2)
- Urban water supply infrastructures are vulnerable, especially in coastal areas, to climate changes that reduce regional precipitation or that, as a result of this or sea level rise may increase saline intrusion to rivers and aquifers used for water supply. HIGH CONFIDENCE (7.4.3)
- Adaptation can reduce possible damages from climate change vulnerabilities in industry, settlement, and society, and in many cases adaptation options are available for industry, settlement, and society that are not being adopted. VERY HIGH CONFIDENCE (7.6)
- Prospects for adaptation can depend on receiving a relatively strong signal about risks from a lack of action, which is often associated with extreme weather events. HIGH CONFIDENCE (7.6)
- Adaptation depends substantially on the competence and capacity of local governments and other institutions, and their relationships, along with access to financial and other resources. VERY HIGH CONFIDENCE (7.4.3, 7.6)
- Climate change is likely in many areas to increase pressures on governmental infrastructures and institutional capacities and to raise social equity concerns. VERY HIGH CONFIDENCE (7.4.5, 7.6.5)
- Technological innovation for climate change adaptation comes very largely from industry and services, motivated by market signals. It may not be well-matched with climate change adaptation needs and residual uncertainties. HIGH CONFIDENCE (7.6)

Issues of these sorts are important to government policymakers and other decision-makers and citizens across the world; but the existing research literatures are severely limited, especially regarding implications of different rates and magnitudes of climate change for vulnerabilities of industry, settlements, and society in various future time frames. If answers to impact questions about vulnerabilities and adaptive capacities are to be improved in the near future, substantially more support for research on human system impacts and adaptive responses will be required.

7.1 Introduction

7.1.1 Key issues

Climate change and sustainable development are linked through their interactions in industries, human settlements, and society. Many of the forces shaping carbon *emissions* – such as economic growth, technological transformations, demographic shifts, lifestyles, and governance structures -- also underlie diverse pathways of development, explaining in part why industrialized countries account for the highest share of carbon emissions. The same drivers are also related to climate change *impacts*, explaining in part why some regions and sectors, especially from the developing world, are more vulnerable to climate change than others because they lack financial, institutional, and infrastructural capacities to cope with the associated stresses (O'Brien and Leichenko 2003). Settlements and industry are often key focal points for linkages between mitigation and adaptation; for instance, efficient buildings can help in adapting to changing climate, while this adaptation may involve increased or decreased energy use and greenhouse gas emissions associated with climate conditioning (Hough 2004).

Industries, settlements, and human society are accustomed to variability in environmental conditions, and in many ways they have become resilient to it when it is a part of their normal experience. Environmental changes that are more extreme or persistent than that experience, however, can lead to vulnerabilities, especially if the changes are not foreseen and/or if capacities for adaptation are limited; and the IPCC Third Assessment Report (IPCC 2001a) reported that climate change would increase the magnitude and frequency of weather extremes.

The central issues for industry, settlement, and society are whether climate change impacts are likely to require responses that go beyond normal adaptations to varying conditions, if so for whom, and under what conditions responses are likely to be sufficient to avoid serious effects on people and the sustainability of their ways of life. Recent experiences such as Hurricane Katrina suggest that these issues are salient for developed as well as developing countries (Figure 7.1).

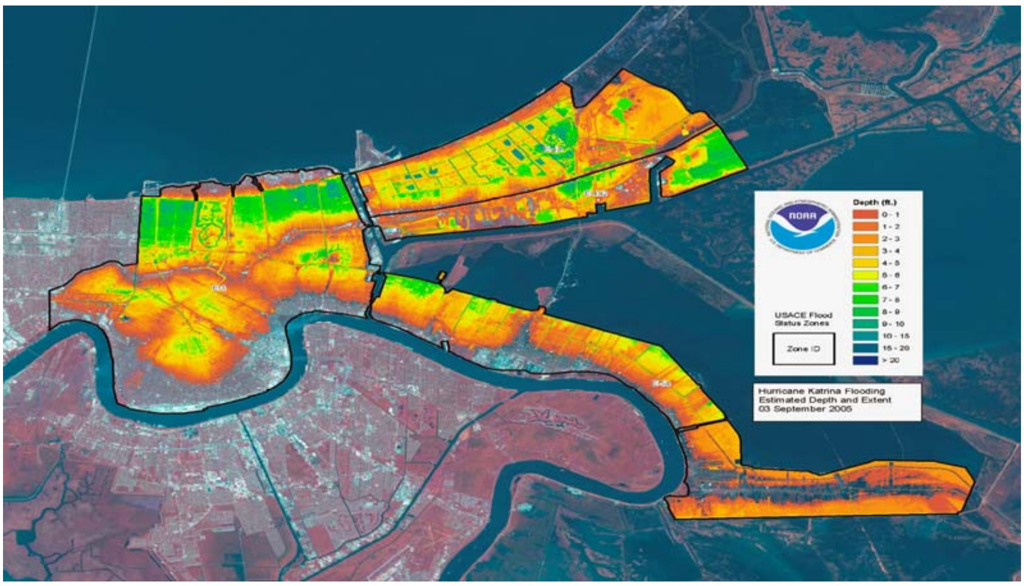

Figure 7.1: *Flood depths in New Orleans, USA, on September 3, 205, five days after flooding from Hurricane Katrina, in feet (0.3 meter).*

Scale matters in at least three ways when assessing the impacts of climate change on human settlements, industry and energy. First, climate change is one of a set of multiple stresses operating at diverse scales in space and through time. Second, both the exposure to climate change and the distribution of climate sensitive settlements and industrial sectors vary greatly across geographic scale. The primary social and economic conditions that influence adaptive capacity also differ with scale, such as access to financial resources. One could say, for instance, that at a national scale industrialized countries such as the UK and Norway can cope with most kinds of gradual climate change, but focusing on more localized differences can show considerable variability in stresses and capacities to adapt (Environment Canada, 1997, Kates and Wilbanks 2003, London Climate Change Partnership 2004, O'Brien, Sygna and Haugen 2004; Ruth, Donaghy, and Kirshen 2006). Third, temporal scale is a critical determinant of the capacity of human systems to adapt to climate change: for instance, rapid changes are usually more difficult to absorb without painful costs than gradual change (Chapter 16).

7.1.2 Scope of the chapter

This chapter's topic of "industry, settlements, and society" is clearly very broad; and many of the components of the chapter, such as industry and services, settlements, financial issues, and social issues, are so heterogeneous that each could be the subject of a separate chapter. Very briefly, however, the chapter will summarize and assess the literature relevant to the impacts of climate change on the structure, functioning, and relationships of all these topics.

The chapter (1) identifies current and potential vulnerabilities and impacts of climate change on industrial, service, and infrastructure sectors, human settlements, and human societies; (2) assesses the current knowledge about the costs of possible impacts; and (3) considers possible adaptive responses. In general, it emphasizes that climate change impacts, adaptation potentials, and vulnerabilities are context-specific, related to both characteristics and development pathways of the location or sector involved.

7.1.3 Human systems in context

Human systems include social, economic, and institutional structures and processes. Related to industry, settlement, and society, these systems are diverse and dynamic. They tend to revolve around aims of humanity such as survival, security, well-being, equity, and progress; and in these regards weather and climate are often of secondary importance as sources of benefits or stresses. More important are such issues as access to financial resources, institutional capacities, and potentials for conflict (Thomas and Twyman 2005; Ocampo and Ocampo 2003) and such stresses as rapid urbanization, disease, and terrorism. It is in its complex interactions with these kinds of social contexts that climate change can make a difference, easing or aggravating multiple stresses and in some cases potentially pushing a multi-stressed human system across a threshold of sustainability (Wilbanks, 2003c).

In most cases, climate (and thus climate change) affects human systems in three principal ways. First, it provides a context for climate-sensitive human activities ranging from agriculture to tourism. For instance, rivers fed by rainfall enable irrigation and transportation and can enrich or damage landscapes. Second, climate affects the cost of maintaining built climates for human life and activity; clearly, higher temperatures increase costs of cooling reduce costs of heating. Third, climate interacts with other types of stresses on human systems, in some cases reducing stresses but in other cases exacerbating them. For example, drought can contribute to rural-urban migration, which, combined with population growth, increases stress on urban infrastructures and socioeconomic conditions. In all of these connections, extreme climate events and other abrupt changes affect human systems more severely, because they offer less time for adaptation.

7.1.4 Conclusions of the IPCC Third Assessment Report

The Third Assessment Report of IPCC Working Group II (TAR) included a chapter on Human Settlements, Energy, and Industry (IPCC 2001a) and also a separate chapter on Insurance and Other Financial Services (IPCC 2001c). Together, these two chapters in TAR correspond to a part of this one chapter in the Fourth Assessment Report; a substantial part of this chapter is devoted to subject matter not directly addressed in previous IPCC reports.

The first of the TAR chapters (Chapter 7) was largely devoted to impact issues for human settlements, concluding that settlements are vulnerable to effects of climate change in three major ways: through economic sectors affected by changes in input resource productivity or market demands for goods and services, through impacts on certain physical infrastructures, and through impacts of weather and extreme events on the health of populations. It also concluded that vulnerability tends to be a function mainly of three factors: location (coastal and riverine areas at most risk), economy (those dependent on weather-related sectors at most risk), and size (with larger settlements at greater aggregate risk but having more resources for impact prevention and adaptation). The most direct risks are from flooding and landslides due to increases in rainfall intensity and from sea-level rise and storm surges in coastal areas. Although some areas are at particular risk, urban flooding could be a problem in any settlement where drainage infrastructures are inadequate, especially where informal settlement areas lack urban services and adaptive capacities. Rapid urbanization in relatively high-risk areas is a special concern, because it is generally increasing global and regional vulnerability to climate change impacts. Other dimensions of vulnerability include general regional vulnerabilities to impacts (e.g., in polar regions), lack of economic diversification, and fragile urban infrastructures.

Possible impacts of climate change on financial institutions and risk financing were the focus of a separate chapter (Chapter 8) in the TAR. This chapter concluded that climate change is likely to raise the actuarial uncertainty in catastrophe risk assessment, placing upward pressure on insurance premiums and possibly leading to reductions in risk coverage. It identified a significant rise in the costs of losses from meteorological disasters since the early 1980s, which appeared to reflect an increase in catastrophe occurrence over and above the rise in values, exposures, and vulnerabilities (see Chapter 1).

7.2 Current sensitivity/vulnerability

A frequent objective of human societies is to reduce their sensitivity to weather and climate, for example by controlling the climate in buildings within which people live, shop, and work or by controlling the channels and flows of rivers or the configurations of seacoasts. Recent experience with weather variability, however, reminds us that -- at least at conceivable levels of investment and technological development -- human control over climate-related aspects of nature is in some cases limited (see Hurricane Katrina: Box 7.4).

In fact, sensitivities of human systems to climate and climate change abound:

(1) Environmental quality is a case in point, where weather and climate can affect air and water pollution and, in cases of extreme events, exposures to wastes that are hazardous to health. Consider

the interaction between the ambient air temperature of an urban area and its concentration of ozone, which can have adverse health implications (Hogrefe *et al.* 2004; Chapter 8), or effects of hurricane flooding on exposures to health threats (Marris 2005).

(2) Linkage systems, such as transportation and transmission systems for industry and settlements (e.g., water, food supply, energy, information systems, and waste disposal), can also be subject to climate-related extreme events such as floods, landslides, fire, and severe storm damage. Such exposed infrastructures as bridges and electricity transmission networks are especially vulnerable, as in the experience of Hurricane Georges in 1998, which threatened port and oil storage facilities in the Dominican Republic (REC, 2004), or the 2005 experience with Hurricane Katrina (Box 7.4: section 7.4.3). Other physical infrastructures can be affected by weather and climate as well. For example, the rate of deterioration of external shells of building structures is weather-related, depending on the materials used, and buildings are affected by water-logging related to precipitation patterns. Another kind of impact is on demands for physical infrastructures: for instance, demands for water supplies and energy supplies related to temperature.

(3) Social systems are also vulnerable, especially to extreme events (e.g., Box 7.1). Storms and floods can damage homes and other shelters; and risks of such impacts shape structures for emergency preparedness, especially where impacted populations have a strong influence on policy-making. Climate is related to the quality of life in complex ways, including recreational patterns, and changes in temperature and humidity can change health care challenges and requirements (Chapter 8).

Box 7.1: Impacts of the 2003 Heat Wave In Europe

The summer 2003 heat wave in Western Europe affected settlements, economic services, and some aspects of societies in a variety of ways. Economically, this extreme weather event created stress on health, water supplies, food storage, and energy systems. During the heat wave in France, electricity became scarce, construction activities had to be modified, and 25-30 percent of food-related establishments found their cooling systems to be inadequate (Pelletier *et al.* 2003). The impact issues were mainly health and health service related (see Chapter 8); but they were also associated with settlement and social conditions, from inadequate climate conditioning in buildings to the fact that many of the dead were elderly people, left alone while their families were on vacation. Electricity supply was affected by a scarcity of power plant cooling water. In addition, the crisis illustrated how government infrastructures can be unable to deal with complex, relatively sudden environmental challenges (Lagadec 2004).

Moreover, some references suggest relationships between weather and climate on the one hand and social stresses on the other, especially in urban areas where the poor lack access to climate-controlled shelters (e.g., the term “long, hot summers” associated in the 1960s in the United States with summer urban riots; also see Arsenault 1984 and Box 7.1). In some cases, the tolerance for climatic variation is limited, for example in tightly-coupled urban systems where low capacity drinking water systems have limited resilience in the face of drought or population growth, not only in developing countries but also in industrialized countries. Another case is the sensitivity of energy production to heat waves and drought; in the summer of 2003, the level of many French rivers dropped so low that the cooling of nuclear power plants was endangered and some cases came close to a mandatory shutdown (Pelletier *et al.* 2003).

(4) Climate can be a factor in an area's comparative advantage for economic production and growth. Climate affects some of an area's assets for economic production and services, from agricultural and fibre products (Chapter 5) to tourist attractions. Climate also affects costs of business operation, e.g., costs of climate control in office, production, and storage buildings. And not only can climate affects an area's own economic patterns; it can also affect the competitive position of its markets and competitors.

(5) Impacts of climate on industry, settlements, and society can be either direct or indirect. For instance, temperature increases can affect air pollutant concentrations in urban areas, which in turn change exposures to respiratory problems in the population, which then impact health care systems. Tracing out such second, third, and higher-order cascading indirect impacts is a significant challenge.

(6) Impacts are not equally experienced by every portion of an industrial structure or a population. Some industrial sectors and the very young, the very old, and the very poor tend to be more vulnerable to climate impacts than the general economy and population (Box 7.1). Some of these differences are also regional, more problematic in developing regions and intricately related to development processes (ISDR 2004).

Tourism is an example of an economic sector whose sensitivity to climate has been comprehensively analyzed (Besancenot 1989 Martin 2005; the emphasis on climate change is, however, more recent (Scott, ones *et al.*, 2005). For example, sun, sand, and sea travel decisions are often based on the desire for warm and sunny environments, while winter tourism builds on expectations of snow and snow-covered landscapes. Tourism is thus sensitive to a range of climate variables such as temperature, hours of sunshine, precipitation, humidity, and storm intensity and frequency (Matzarakis *et al.* 2001; Matzarakis *et al.* 2004), along with the consequences that may follow, such as fires, landslides, and coastal erosion.

In addition, the environmental resources on which tourism depends are sensitive to climate change. For instance, the availability of freshwater can be a costly challenge for tourism (Gössling and Hall 2005; Chapters 6 and 16), particularly if managed through water imports or desalination. Tourism is in competition with other uses of water (such as agriculture) for recreation and watersports and is based on high quality water supplies, while it simultaneously threatens water quality through discharges of untreated sewage.

Snow and snow cover are essential resources for winter sports, and have (like water in lakes, streams and oceans) a high amenity value. Numerous studies in the past decade have dealt with the climatic sensitivity of winter destinations assessing how far the diminution of snow cover, varying according to altitude and geographical situation, shortens seasons and endangers marginal destinations. Biodiversity might attract tourists for reasons of exoticism; often, as in the case of tropical forests or coral reefs, it might be the precondition for special interest tourism (Chapter 4). In these ways and others, climate is often related to aesthetic qualities of landscapes that are valued by tourist populations.

7.3 Assumptions about future trends

The use of scenarios to explore future effects of climate change on industry, settlement, and society has not been a high priority, as the SRES framework tends to be generic and qualitative regarding human system assumptions and trends (Chapter 2).

A key future condition relates to demographic dynamics. According to the latest United Nations projections, even as the rate of population growth continues to decline, the world's total population will rise substantially. The total is expected to reach between 8.7 and 9.3 billion in 2030 (UN, 2005). According to the Medium Variant projection, the peak will be reached in 2075, at 9.2 billion, followed by a slight decline (UN 2004). Practically all of these people live in settlements, many depending on industry, services, and infrastructures for jobs, well-being, and mobility.

Most population growth will take place in cities. There will be differences between developed and other nations, accompanied by differences in economic growth and income distribution (UN 2005**;** Montgomery *et al.* 2004**).** The most dramatic population growth will occur in urban areas of developing countries, where populations are expected to double during the next 50 years (Table 7.1). Features of development relevant to adaptation, such as access to resources, location and institutional capacity, are likely to be predominantly urban.

Risk prone settlements such as in coastal areas are expected to experience major increases in population, urban area and economic activity, especially in developing countries (Chapter 6). Growing population and wealth in exposed coastal locations may result in increased economic and social damage, especially in less developed countries, as shown by Hurricane Jeanne in Haiti (Pielke *et al.* 2005).

Table 7.1: *Urban indicators*

	Percentage Urban				*Urbanization rate (percentage)*		*Doubling time (Years)*	
Year	*1950*	*1975*	*2000*	*2030*	*1950-2000*	*2000-2030*	*1950-2000*	*2000-2030*
Northern America	63.9	73.8	77.4	84.5	0.38	0.30	-	-
Latin America and the Caribbean	41.9	61.4	75.4	84.0	1.18	0.36	-	-
Oceania	61.6	72.2	74.1	77.3	0.37	0.14	-	-
Europe	52.4	67.3	73.4	80.5	0.68	0.31	-	-
Asia	17.4	24.7	37.5	54.1	1.53	1.23	45	57
Africa	14.7	25.2	37.2	52.9	1.86	1.17	37	59

Source: United Nations Population Division, World Urbanization Prospects. The 2001 Revision Note: Major areas are ordered according to the percentage urban in 2000.

Some scholars have suggested that the world is at a turning point from which a broad range of possible futures could unfold (Gallopin *et al.* 1997). At least two of these sets of futures are useful to explore potential impacts and adaptation responses by industry, settlement, and society to climate change: the four SRES scenarios and a "barbarization" scenario (Chapter 2 and Gallopin *et al.* 1997). In all SRES scenarios, global GDP increases and there is economic convergence, but at differing rates. The future will be more affluent, and income differences will contract. Technological development will follow different pathways (e.g. slow improvements in efficiency in A2, improved resource efficiency and dematerialization in B1). There will be relatively more institutional capacity to implement environmental policies with different emphases, but economic development will be "central in determining adaptive capacity" (Toth and Wilbanks 2004).

In the "barbarization" scenario "absolute poverty increases and the gap between rich and poor – both within and between countries – continues to grow, national governments lose relevance and power relative to transnational corporations and global market forces, and environmental conditions continue to worsen notwithstanding some successes, notably in the richest countries," (Gallopin *et al.* 1997: 29-33). In such a scenario, growing gaps between developed and poor nations (and within them) may limit the current and future ability of industry, settlements, and societies in less developed areas to adapt to climate change, and they may add stresses associated with political and social conflict, as growing disparities motivate actions to reduce those disparities

In the SRES scenarios, societies and economies will have relatively more institutional capacity to implement environmental policies, which together with economic development will enhance adaptive capacity. By contrast, in the barbarization scenario, increasing gaps between rich and poor sectors and communities may limit the ability of societies and economies in less developed areas to adapt to climate change, adding stresses associated with political and social conflict.

7.4 Key future impacts and vulnerabilities

The ability to project how climate change may affect industry, settlement, and society is limited by uncertainties about climate change itself at the relatively fine-grained geographical and sectoral scale and also by uncertainties about trends in human systems over the next century *regardless of climate change* (Chapter 2). In some cases, uncertainties about socioeconomic factors such as technological and institutional change over many decades undermine the feasibility of comparing future prospects involving *considerable* climate change with prospects involving *relatively little* climate change. Typically, therefore, research focuses on vulnerabilities to impacts of climate change (defined as the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a perturbation or source of stress: Turner *et al.* 2003; also see Clark *et al.* 2000) rather than on projections of impacts of change on evolving socioeconomic systems.

Beyond this, climate change will often not be a primary factor in changes for industry, settlement, and society. Instead, it will have an impact by modifying other more significant aspects of ongoing socioeconomic changes. This may have either an exacerbating or an ameliorating effect in influencing overall vulnerabilities to multi-causal change. It is especially difficult to associate levels of climate change impacts or their costs with a specified number of degrees of mean global warming or with a particular time horizon such as 2050 or 2080, when so many of the main drivers of impacts and costs are not directly climate-related, even though they may be climate-associated, and when impacts are often highly localized.

7.4.1 General effects

Certain kinds of effects follow from particular expressions of climate change, wherever those phenomena occur. For example, increased precipitation in already well-watered areas can increase concerns about drainage and water-logging (Parkinson and Mark 2005). Sea-level rise affects land uses and physical infrastructures in coastal areas. Moreover, such changes in conditions can affect requirements for public health services (Chapter 8), water supplies (Chapter 3), and energy services (such as space heating and cooling). Effects can either be cumulative (additive), as in losses of property, or systematic (affecting processes), as in damages to institutions or systems of production.

Besides gradual changes in climate, along with climatic extremes, human systems are affected by a change in the magnitude, frequency, and/or intensity of storms and other extreme weather events, as well as changes in location. In fact, some assessments suggest that many impact issues are more directly associated with climatic *extremes* than with *averages* (NACC, 2000). Of special concern is the possibility of abrupt climate changes not anticipated by normal response planning (Chapter 19), which can be associated with locally or regionally catastrophic impacts if they were to occur.

Although localities differ, interactions between climate change and human systems are often substantively different for relatively developed, industrialized countries vs. less developed countries and regions. As a broad generalization, in many cases possible negative impacts of climate change pose risks of higher total *monetary* damages in industrialized areas but higher total *human* damages in less-developed areas, although such events as Hurricane Katrina show that there are exceptions.

Not all implications of possible climate change are negative. For instance, along with possible carbon fertilization effects (Chapter 5), many mid and upper-latitude areas see quality-of-life benefits from winter warming, and some areas welcome changes in precipitation patterns, although such changes may have other social consequences. The greater proportion of the research literature, however, is related to possible adverse impacts. Climate impact concerns include environmental quality (e.g., more or less ozone, water logging, or salinization), linkage systems (e.g., threats to water supply or power supply), societal infrastructures (e.g., changed energy/water/health requirements, disruptive severe weather events, reductions in resources for other social needs, environmental migration, placing blame for adverse effects, changes in local ecologies that undermine a sense of place), physical infrastructures (e.g., flooding, storm damage, changes in the rate of deterioration of materials, changed requirements for water or energy supply), and economic infrastructures and comparative advantages (e.g., costs and/or risks increased, markets or competitors affected).

Economic sectors, settlements, and social groups can also be affected by climate change response policies. For instance, certain greenhouse gas stabilization strategies can affect economies whose development paths are dependent on abundant local fossil fuel resources, including economic sectors involved in mining and fuel supply as well as fuel use.

In many cases, the importance of climate change effects on human systems seems to depend on the geographic (or sectoral) scale of attention (Association of American Geographers, 2003; Wilbanks, 2003b). At the scale of a large nation or a large region, at least in most industrialized nations, the economic value of sectors and locations with low levels of vulnerability to climate change greatly exceeds the economic value of sectors and locations with high levels of vulnerability, and the capacity of a complex large economy to absorb climate-related impacts is often considerable. In many cases, therefore, estimates of aggregate damages of climate change (other than major abrupt changes) are often rather small as a percentage of economic production (e.g., Mendelsohn 2001). On the other hand, at a more detailed scale, from a small region to a small country, many specific localities, sectors, and societies can be highly vulnerable, at least to possible low-probability/high-consequence impacts; and potential impacts can amount to very severe damages. It appears that large-regional or national estimates of possible impacts may give a different picture of vulnerabilities than an aggregation of vulnerabilities defined at a small-regional or local scale.

7.4.2 Systems of interest

Guidance for the preparation of the IPCC Fourth Assessment Report requested particular attention by this chapter to five systems of interest: industry, services, utilities/infrastructure, human settlement, and social issues. Chapter 5 of this report deals with impacts and adaptation on the food, fibre and forest products sectors, and chapters 9 to 16 deal with impacts and adaptation in global regions.

7.4.2.1 Industry

For this chapter, industry includes manufacturing, energy supply and demand, mining, construction, and related informal production activities in developing economies. Other sectors sometimes included in industrial classifications, such as wholesale and retail trade, transport and communication, and real estate and business activities, are included in the categories of services and infrastructure (below). Together, industry and economic services account for over 95 percent of GDP in highly developed economies and between 50 and 80 percent of GDP in less developed economies.

Industrial sectors are generally thought to be less vulnerable to the impacts of climate change than other sectors, such as agriculture and water services. This is in part because their sensitivity to climatic variability and change is viewed as being comparatively lower and in part because industry is seen as having a high capacity to adapt in response to changes in climate. The major exceptions are industrial facilities located in climate-sensitive areas (such as coasts and floodplains), industrial sectors dependent on climate-sensitive inputs (such as food processing), and industrial sectors with long-lived capital assets (Ruth *et al*, 2004).

Industrial activities are vulnerable to direct impacts such as temperature and precipitation changes. For instance, weather-related highway accidents translate into annual losses of at least $1 billion annually in Canada, while more than a quarter of air travel delays in the United States are weather-related (Andrey and Mills 2003). Moreover facilities across a range of industrial sectors are often located in areas vulnerable to extreme weather events (including flooding, drought, high winds), as the Katrina tropical cyclone clearly demonstrated. In other cases, climate change could lead to reductions in the direct vulnerability of industry and infrastructures. For instance, fewer freeze-thaw cycles in temperate regions would lead to less premature deterioration of road and runway pavements (Mills and Andrey 2002). On the other hand, where extreme events threaten linkage infrastructures such as bridges, roads, pipelines, or transmission networks, industry can experience substantial economic losses. There exist relatively few quantified assessments of these direct impacts, suggesting an important role for new research (Eddowes *et al.* 2003).

Less direct impacts on industry can also be significant. For instance, sectors dependent on climate-sensitive inputs for their raw materials are likely to be affected: e.g., pulp and paper production dependent on cheap and reliable supplies of forest fibre. In the longer term, as the impacts of climate change become more pronounced, regional patterns of comparative advantage of industries closely-related to climate-sensitive inputs could be affected, influencing regional shifts in production (Easterling *et al.* 2004). A range of direct and indirect impacts on three different classes of industry is identified in Table 7.2.

In developing countries, industry is often small-scale and informally organized. Impacts of climate change are likely to depend on the determinants identified in the TAR: location in vulnerable areas, dependence on inputs sensitive to climate, and access to resources to support adaptive actions. It is difficult to generalise about the vulnerability and adaptive capacity of small-scale industrial activities, whether in developed or developing country settings. Many of these activities will be less concerned with climate risks and have a high capacity to adapt, while many others will become more vulnerable to direct and indirect impacts of climate change.

An example of an industrial sector particularly sensitive to climate change is energy. Climatic change would likely affect energy consumption behaviour in many parts of the world. In warmer regions, an increased energy requirement for space cooling is expected. Temperature increases in the regions where space heating is required in winter may result in some savings. Net energy requirement estimates at a national scale, however, can mask differences in energy sources. The main source of energy for cooling is electricity, while sources of energy for space heating include coal, oil, gas, biomass, and electricity. Regions with substantial requirements for both cooling and heating could

Table 7.2: *Direct and indirect climate change impacts on industry.*

Sector	Direct impacts	Indirect impacts	References
Built Environment: Construction, Civil Engineering	On internal environments of buildings: -Energy costs -External fabric of buildings -Structural integrity -Construction process -Service infrastructure	- Climate-driven standards and regulations - Changing consumer awareness and preferences	Camillieri, 2000; Graves and Phillipson, 2000; Consodine, 2000; Sanders and Phillipson, 2003; Spence *et al.*, 2004; Brewer, 2005; Kirshen *et al.* 2005
Infrastructure Industries: Energy, Water, Telecommunications, Transport (see section 7.4.2.3)	- Structural integrity of infrastructures - Operations and capacity - Control systems	- Changing demand	Andrey and Klapper, 2003; Eddowes *et al.*, 2003; UK Water Industry Research, 2004; Fowler, 2005
Natural Resource Intensive Industries: Pulp and Paper, Food Processing, etc.	- Risks to and higher costs of input resources	- Supply chain shifts and disruption	Broadmeadow *et al*, 2005; Anon, 2004

find that net annual electricity demands increase while demands for other heating energy sources decline. Hadley *et al.* (2004) estimate that there would be large regional differences in impacts of warming on energy demand in USA, with a total of 40 GW per year required by 2025 to meet additional electricity requirements. In addition to the total energy demand, seasonal variation in the demand is also important. In some cases, due to infrastructure limitations, peak demand could go beyond the maximum capacity of the transmission system.

Tol (2002) has estimated the effects of climate change on the demand for global energy, extrapolating from a simple country-specific (United Kingdom) model that relates the energy used for heating or cooling to degree days, per capita income, and energy efficiency. According to Tol, by 2100 benefits (reduced heating) will be about 0.75% of gross domestic product (GDP) and damages (increased cooling) will be approximately 0.45%, although it is possible that migration from heating-intensive to cooling-intensive regions could affect such comparisons in some areas.

Many sectors affected by climate change would have indirect impacts on the energy sector, e.g., with a temperature increase, the water requirement for agriculture is expected to rise (Chapter 4). In addition, water consumption by society at large will increase with higher temperatures, resulting in higher water requirement in settlements. Combined, these changes would result in a higher demand for energy for pumping and irrigation, although this might be countered by increase in rainfall and humidity in some regions.

In addition to direct and indirect *demand*-side impacts discussed above, the *supply* side of the energy sector is also likely to be affected by climate change. TAR concluded that hydropower generation is the energy source that is likely to be impacted because it is sensitive to the amount, timing, and geographical pattern of precipitation as well as temperature (rain or snow, timing of melting). Reduced stream flows are expected to jeopardize hydropower production in some areas, whereas greater stream flows, depending on their timing, might help it.

According to Breslow and Sailor (2002), there is a need to consider climate variability and long term climate change in sitting wind power facilities by including estimates of vulnerabilities in the wind power site selection decision process. Other supply-side vulnerabilities include possible impacts of precipitation changes on potentials for biomass energy and impacts of severe weather events on wind power stations, electricity transmission and distribution networks, oil product storage facilities, and off-shore oil production. Fossil-fuel production facilities (particularly off-shore units) and energy transportation systems (shipping, pipelines, etc.) are also vulnerable. Soil subsidence caused by the melting of permafrost is a risk to gas and oil pipelines, electrical transmission towers, nuclear power plants, and natural gas processing plants in the arctic region (Nelson *et al.* 2001). During the catastrophic European heat waves of 2003, nuclear power plant activity had to be curtailed because of elevated cooling-water temperatures (Pelletier *et al.*2003).

Policies for reducing GHG emissions are expected to affect the energy sector in many countries. For instance, Kainuma *et al.* (2004) compared a reference scenario with six different GHG reduction scenarios. In the reference scenario, the use of coal increases from 18% in 2000 to 48% in 2100. In contrast, the world's final energy demand in strong mitigation scenarios decreases to nearly half that in the reference scenario in 2100. This reduction comes about mainly from reducing coal use, whereas the share of electricity increases. Kuik (2003) has shown that, for Europe, there is a trade-off between economic efficiency, energy security and carbon dependency for the EU.

7.4.2.2 Services

Services include retail and wholesale commerce and trade, real estate and business activities, financial services, and such sectors of the economy as recreation and tourism. Transportation and communication infrastructures are included in 7.4.2.3, and government services are included in the sections on human settlement and social issues.

Some impacts of climate change on services are quite obvious, such as changes in requirements for heating and cooling buildings (including schools and hospitals). In a larger sense, however, impact vulnerabilities tend to be focused on certain climate-sensitive sectors such as tourism and finance, while many retail and commercial services are located in areas especially vulnerable to such climate impacts as extreme storms and sea level rise.

Possible impacts of climate change on interregional trade are still rather speculative. Climate change could affect trade by reshaping regional comparative advantage related to (a) general climate-related influences (Figure 7.2), such as on agricultural production, (b) exposure to extreme events combined with a lack of capacity to cope with them, or (c) effects of climate change mitigation policies that might create markets for emission-reduction alternatives. In an era of increased globalization, small changes in price structures (including transportation costs) could have amplified effects on regional economies. Beyond actual climate change impacts, a perception of future impacts or regulatory initiatives may affect investment and trade.

Climate change may also disrupt transport activities that are important to national supplies as well as international trade. For instance, extreme events may temporarily close ports or transport routes and damage infrastructure critical to trade. Increases in the frequency or magnitude of extreme weather events could amplify the costs to transport companies and state authorities from closed roads, train delays and cancellations, and other interruptions of activities (O'Brien *et al.* 2005). It appears that there may be linkages between climate change scenarios and international trade scenarios, such as the Doha Development round (Oxley 2002) and regional and subregional free trade agreements.

Retail and other commercial services have often been neglected in climate change impact studies. Climate change has the potential to affect every link in the supply chain, including the efficiency of the distribution network, the health and comfort of the workforce (Chapter 8), and patterns of consumption. In addition, climate change policies such as carbon taxes could raise industrial and transportation costs, alter world trade patterns, and necessitate change in infrastructure and design technology.

As one example, distribution networks for commercial activities would be negatively affected by an increase in hazardous weather events. Strong winds can unbalance high-sided vehicles on roads and bridges, and may delay the passage of goods by sea. Coastal infrastructure and distribution facilities are vulnerable to inundation and flood damage. In contrast, transportation of bulk freight by inland waterways, such as the Rhine, can be disrupted during droughts (Parry 2000). Further, climate variation creates short-term shifts in patterns of consumption within specific retail markets, such as in the clothing and footwear market (Agnew and Palutikof, 1999). However, most impacts entail transfers within the economy (Subak *et al.*, 2000) and are transitory.

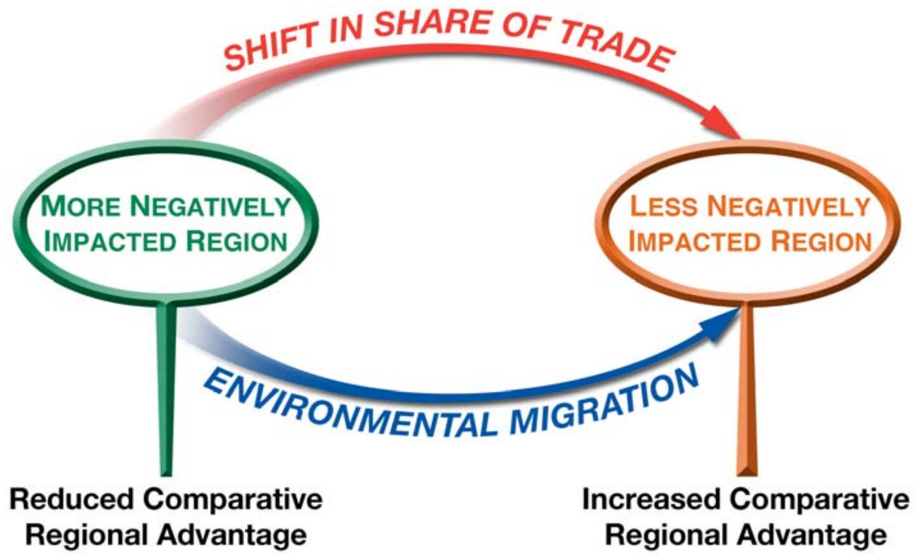

Figure 7.2: *General Effects of Climate Change on International Trade: greater net benefits from climate change are likely to show trade benefits, along with environmental in-migration.*

Perishable commodities are one of the most climate-sensitive retail markets (Lin and Chen, 2003). It is possible that climate change will alter the sourcing and processing of agricultural produce; and carbon tax legislation may further alter the geographical distribution of raw materials and product markets.

A substantial research literature has assessed the consequences of climate change for international tourist flows: e.g., Agnew and Viner 2001 and Hamilton 2005, for the tourist industries of nations (Becken 2005; Ceron 2005), destinations (Belle 2005); attractions, such as national parks (Jones 2006), and tourism activities (Perry 2004; Jones 2006) or sectors of tourism such as ski-tourism (e.g. Elsasser 2002; Fukshima 2003; Hamilton 2003).

Likely effects of climate change on tourism vary widely according to location, including both direct and indirect effects. Regarding direct effects, climate change in temperate and northern countries seems to mean a northward shift in conditions favourable to many forms of tourism (Chapter 15), other than conditions related to snow. This might, for instance, lead to more domestic tourism in NW Europe (Chapter 12; Agnew, Viner, 2001; Maddison, 2001) and in the middle latitudes of North America (Chapter 14). If winters turn out to be milder but wet and windy, however, the gains to be expected are less obvious (Ceron, 2000). Areas dependent on the availability of snow are among those most vulnerable to global warming (Chapters 11, l2, and 14). In summer, destinations already hot could become too hot for affordable comfort (Chapter 12); but tropical destinations might not suffer as much from an increase in temperatures, since tourists might expect warm climates as long as indoor comfort is assured (Gossling and Hall 2005b). Regarding low-lying islands, sea-level rise and increasingly frequent and intense weather extremes might become of great importance in the future (Chapter 16). Extreme climate events, such as tropical storms, could have substantial effects on tourist infrastructure and the economies of small-island states (London 2004).

Indirect effects include changes in the availability of water and costs of space cooling, but at least as significant could be changes in the landscape of areas of tourist interest, which could be positive or negative (Sasidharan, Yarnal, Yarnal, Godbey, 2001; see Ch 14). Warmer climates open up the possibility of extending exotic environments (such as palm trees in western Europe), which could be considered by some tourists as positive. Droughts and the extension of arid environments (and the effects of extreme weather events) might discourage tourists, although it is not entirely clear what they consider to be unacceptable. In tropical environments, destruction due to extreme weather events (buildings, coral reefs, trees and plants) are a concern, but vegetation and landscape tend to recover relatively quickly with the notable exception of eroded beaches and damaged coral reefs. One indirect factor of considerable importance is energy prices, which affect both the cost of providing comfort in tourist areas (Becken, Simmons, Frampton 2001) and the cost of travelling to them (Becken, Simmons, Frampton 2003). This effect can be especially significant for smaller, tourist-oriented countries, often in the developing world; for instance, receipts from international tourism account for 39% of GDP in the Bahamas, but only 2.4% for France (World Tourism Organization, 2003b).

The environmental context in which tourism will operate in the future involves considerable uncertainties. The range of possible scenarios is great, and there have been some attempts to link the future of tourist activities to SRES (Chapter 14) or other scenarios (Chapter 11). In these scenarios, tourist reactions to climate change are assumed to be constant, notwithstanding the fact that these responses are currently not satisfactorily understood. Climate change is likely to directly and indirectly influence human activities in the Arctic region, including tourism, oil and gas exploration, and transport (ACIA 2004).

Insurance is a service sector closely connected with possible damages from climate change, especially more intense and/or frequent extreme weather events. The insurance market includes a variety of entities who may have different perspectives on risk costs. In the purchase of reinsurance, for example, reinsurers will tend to be more pessimistic about catastrophe risk-costs than the insurers who are ceding the risk, and this perspective has been highlighted in leadership to warn of the potential impacts of climate change (Swiss Re 2004; Munich Re 2005).

National risk financing systems in place today have been shaped by past catastrophes (Box 7.2), especially the occurrence of major floods. Different climate change scenarios imply different futures for the role of insurance, depending on how insurance coverage expands with economic growth and on where (by region and situation) increases in the direct or indirect costs of catastrophes are predicted. If risk increases under climate change overall the insurance industry can be expected to expand in the volume of premium collected, claims paid, and income (where insurers overcome consumer, regulatory and cyclical pressures to restrict increases in insurance rates).

Where increased losses lead insurers to reduce the availability of insurance, unless there is a compensatory increased government participation in risk financing, there will be impacts on local and regional economic activity, including housing and industrial activity, unless government expands its risk protection roles. In particular in developed countries, governments are also likely to be the principal funders of risk mitigation measures (e.g., flood defences). In the developing world, the role of insurers and governments in offering risk protection is generally limited.

Box 7. 2: The Impact of Recent Hurricane Losses

The $15.5 billion insurance loss of Hurricane Andrew in 1992 ($23Bn adjusted to 2006 values) remains an exemplar of the consequences on the insurance industry of a catastrophe more severe than had been anticipated, leading to the insolvency of 12 insurance companies and significant market disruption. However, after major adjustments, the private insurance market re-expanded its role, so that in the four hurricanes of 2004 (with a Florida loss totalling $21.5 billion) only one small insurance company failed, and there was little impact on reinsurance rates, largely because state backed insurance and reinsurance mechanisms absorbed a significant proportion of the loss. However, a far greater proportion of the $55Bn of insured losses from the 2005 hurricanes in Mexico and the US fell onto the international reinsurance market, leading to at least two situations where medium sized reinsurers are unlikely to remain independently viable.

As reinsures sit outside any national regulatory system of price controls, they are free (within the competitiveness of the market) to raise prices and reduce coverages after major catastrophe losses. However, the rates charged by reinsurers also have to be loaded for unrecognized and unquantified sources of losses that may fall within the terms of the insurance coverage, although after a decade of rising losses (from both natural and man-made catastrophes) insurance is generally becoming more restrictive in what is covered. Insurance rates in many areas rose after 2001 so that while the 2004 year was both the worst (up to that time) for US catastrophe losses it was also the most profitable year ever for US insurers (Dyson 2005).

Insurance organizations also manage very large portfolios of investments and are therefore concerned with all those factors that affect the value of these investments and in particular where investment returns might be affected by the largest catastrophe losses. For all sectors of the investment community, areas potentially affected by climate change related risks include hydroelectric projects, irrigation and agriculture, tourism and the construction industry (UNEP, 2002**)**: the last of these is sometimes used as an offsetting hedge by insurers against catastrophe losses. In high carbon-emitting sectors, such as power generation and petrochemicals, future company values may also be affected by threatened or actual litigation around climate change impacts (Kiernan, 2005). The finance sector, and in particular hedge funds, are significant investors in climate related risks, both via investments in re/insurance companies and through participation in conventional or alternative risk transfer products, e.g., insurance-linked securities such as Catastrophe Bonds and weather derivatives (see Jewson *et al.*).

7.4.2.3 Utilities/infrastructure

Infrastructures for industry, settlements, and society include both "physical" (such as water, sanitation, energy, transportation, and communication systems) and "institutional" (such as shelter, health care, food supply, security, and fire and other forms of emergency protection). In many instances, such “physical” and “institutional” infrastructures are linked. For example, in New York City adaptations of physical water supply systems to possible water supply variability are dependent on changes within the institutions that manage them; conversely, institutions such as health care are dependent to some degree on adjustments in physical infrastructures to maintain effective service delivery (Rosenzweig and Solecki 2001).

These infrastructures are vulnerable in different ways and to different degrees to climate change, depending on their state of development, their resilience, and their adaptability. In general, “wet” and “dry” conditions have different effects; the former (e.g., floods) induce more physical damage, while the latter (e.g., heat waves) tend to have impacts on systems and users that are more indirect.

Often, the institutional infrastructure is less vulnerable as it embodies less fixed investment and is more readily adapted within the time scale of climate change. Moreover, the impact of climate change on institutional infrastructure can be small or even result in an improvement in its resilience; for example, it could lead to increased investment in emergency services.

7.4.2.3.1 Water supplies

Climate change, in terms of means or variations, could affect water supply systems in a number of ways. It could affect water *demand*. Increased temperatures and changes in precipitation can contribute to increases in water demand, for drinking, for cooling systems and for garden watering (Kirshen 2002). If climate change contributes to the failure of small local water sources, such as hand dug wells, or to migration, this may also cause increased demand on other systems. It could affect water *availability*. Changes in precipitation patterns may lead to reductions in river flows, falling ground water tables and, in coastal areas, to saline intrusion in rivers and ground water (Chapter 3). And climate change could *damage the system* itself, including erosion of pipelines by unusually heavy rainfall, river flows or storm surges, although the main category is the damage caused by flooding.

Water supplies are designed for a life of many years, with extra capacity in reserve to respond to future growth in demand (although in practice systems in large urban areas tend to expand in a series of discrete stages reflecting perceptions of near-term needs). Allowance is also made for anticipated variations in demand, such as those occurring with the seasons and with the time of day (Chapter 3). From the point of view of the impacts of climate change therefore, water supply systems are quite resilient in many areas with respect to the relatively small changes in mean values of parameters such as temperature and precipitation which are anticipated for many decades, except at the margin where a change in the mean requires a significant change in the design or technology of the water supply system, e.g., cumulative change that eventually leads to reduced reservoir yields (Harman *et al.* 2005) or saline intrusion into an aquifer or into the lower reaches of a river. An example is Southern Africa (Ruosteenoja *et al.*, 2003), where the city of Beira in Mozambique is already extending its 50 km pumping main a farther 13 km inland to be certain of fresh water.

More dramatic impacts on water supplies are liable to be felt under extremes of weather that could arise as a result of climate change, particularly drought and flooding. Even where water resource constraints, rather than system capacity, affect water supply functioning during droughts, this often results from inappropriate allocation of the resource rather than absolute insufficiency. Domestic water consumption, which represents only 2% of global abstraction (Shiklomanov, 2000), is dwarfed by the far greater quantities required for agriculture. Water supply systems, such as those for large coastal cities, are often downstream of other major users and so are the first to suffer when rivers dry up, whereas under Integrated Water Resource Management they would receive priority in allocation as the value of municipal water use is so much greater than agricultural use that they can pay a premium price for the water (Dinar *et al.* 1997).

Nevertheless, in some industrialized countries with low agricultural but high municipal water demand, additional investment is likely to be needed to counter increasing water resource constraints due to climate change. For example, Severn-Trent – one of the nine English water companies – has estimated that its output is likely to fall by 180 Megalitres/day (roughly 9% of the total) by 2030 due to climate change, making a new reservoir necessary to maintain the supply to Birmingham (Environmental Agency 2004).

Moreover, there is cause for concern in the trends discernible during the last century, by which mean precipitation in all four seasons of the year has tended to decrease in all the main arid and semi-arid regions of the world: e.g., northern Chile and the Brazilian Northeast, West Africa and Ethiopia, the drier parts of Southern Africa, and Western China (Folland *et al.* 2001). If these trends continue, water resource limitations will become more severe in precisely those parts of the world where they are already most likely to be critical.

In addition, flooding by rivers and tidal surges can do lasting damage to water supplies. Water supply abstraction and treatment works are sited beside rivers, because it is not technically advisable to pump raw water for long distances. They are therefore often the first items of infrastructure to be affected by floods. While sedimentation tanks and filter beds may be solid enough to suffer only marginal damage, electrical switchgear and pump motors require substantial repairs after floods, which cannot normally be accomplished in less than a fortnight. In severe riverine floods with high flow velocities, pipelines may also be damaged requiring more extensive repair work.

7.4.2.3.2 Sanitation

Some of the considerations applying to water supply also apply to sewered sanitation systems, but in general the effect of climate change on sanitation is likely to be less than that of water supply. When water supplies cease to function, sewered sanitation also becomes unusable. Sewer outfalls are usually into rivers, and so they and any sewage treatment works are exposed to damage during floods (PAHO, 1998). In developing countries, sewage treatment works are usually absent (WHO/Unicef, 2000) or involve stabilisation ponds, which are relatively resilient. Sea level rise will affect the functioning of sea outfalls, but the rise is slow enough for the outfalls to be adapted, by pumping if necessary, to the changed conditions at modest expense. The main impact of climate change on on-site sanitation systems such as pit latrines is likely to be through flood damage. However, they are more properly considered as part of the housing stock rather than items of community infrastructure. The main significance of sanitation here is that sanitation infrastructures (or the lack of them) are the main determinant of the contamination of urban flood water with faecal material, presenting a substantial threat of enteric disease (Ahern *et al.* 2005).

7.4.2.3.3 Transport, power, and communications infrastructures

A general increase in temperature and a higher frequency of hot summers are likely to result in an increase in buckled rails and rutted roads, which involve substantial disruption and repair costs (London Climate Change Partnership 2004). In temperate zones, less salting and gritting will be required, and railway points will freeze less often. Most adaptation to these changes can be made gradually in the course of routine maintenance, for instance by the use of more heat resistant grades of road metal when re-surfacing. Transport infrastructure is more vulnerable to effects of extreme local climatic events than to such changes in the mean. For instance, 14% of the annual repair and maintenance budget of the newly-built 760 km Konkan Railway in India is spent repairing damage to track, bridges and cuttings due to extreme weather events such as rain-induced landslides. This amounts to more than Rs. 40 million, or roughly US$1 million annually. In spite of preventive targeting of vulnerable stretches of the line, operations must be suspended for an average of 7 days each rainy season because of such damage (Shukla, Kapshe and Garg 2005). Parry *et al.* (2000) provide an assessment of the impact of severe local storms on road transportation, much of which also applies to rail (Table 7.3).

Of all the impacts in this table, the greatest in terms of cost is that of flooding. An example is the flooding of one point on the rail link between Oxford and London, UK, between 13th and 18th December 2000. The financial loss to the railway company due to time delay penalties as a result of this one disruption has been estimated to be at least £1.2 m. (London Climate Change Partnership 2004). This does not include the value of lost time suffered by train passengers. Nevertheless a recent study of Boston USA concluded, with regard to flooding, that the cost of delays and lost trips would be relatively small compared with damage to the infrastructure and to other property (Kirshen *et al.* 2006).

Table 7.3 *Effects and Response Strategies Associated with Storm Interactions with Surface Transportation (adapted from Parry et al. 2000).*

Storm attribute	**Impact**	**Possible adaptation**
Tornadic wind	Structure and vehicle damage/displacement of power loss	Evasion, diversion, closure
Strong winds	Structure damage, debris damage, vehicle instability, visibility reduction, power loss	Design, advisories, caution
Heavy rain	Flooding, visibility reduction, landslides, scour of bridge foundations	Design, advisories, caution, diversion, closure, flood control
Heavy snow/sleet	Closure, impedance, entrapment, visibility reduction	Advisories, caution, diversion, closure, ploughing
Hail	Vehicle damage, impedance	Seek shelter, advisories, caution
Lightning	Structure and circuit damage, power loss, distraction	Design, back-up, caution, advisories

Climate modeling results indicate that there will be substantial changes in arctic areas such as the Barents Sea eco-region over the next 50 years, including a decrease in sea ice concentration and a thinning of sea ice that may open new transport routes (ACIA 2004; Furevik *et al.* 2002). A projected increase in maritime activities in the Barents Sea eco-region due to increased transport of oil and gas from Northwest Russia, combined with increased interest in petroleum reserves in the region, will contribute to an increase in the potential risks involved (PAME 2000). Climate change will interact both cumulatively and synergistically with transport changes to create new challenges for the region's biodiversity (O'Brien *et al.* 2004b).

Infrastructure for power transmission and communications is subject to much the same considerations; it is vulnerable to high winds and ice storms when in the form of suspended overhead cables and cell phone transmission masts, but reasonably resilient when buried underground, although burial is significantly more expensive. In developing countries, a common cause of death associated with extreme weather events in urban areas is electrocution by fallen power cables (Few *et al.* 2004). Such infrastructure can usually be repaired at a fraction of the cost of repairing roads, bridges and railway lines, and in much less time, but its disruption can seriously hinder the emergency response to an extreme event.

7.4.2.4 Human settlement

Climate change will impact human settlement in a variety of profound ways. Numerous city-specific case studies have been done, several of them very extensive. Beyond the general perspectives of TAR (7.1.4); however, relatively little synthesis across the case studies has taken place. Emerging generalizations include that climate change will include increased summer heat stress and more heavy precipitation days in winter, rising sea levels, higher temperatures all year long, and increased risks of drought, storms, wind damage, and flooding (as documented for New York, London, Dhaka and Calcutta) (see London Climate Change Partnership 2004 and Klein *et al.* 2003).

Extreme weather events associated with climate change pose challenges to human settlements, because assets and populations in both developed and developing countries are increasingly located in coastal areas, slopes, ravines and other risk-prone regions (Freeman and Warner 2001, Bigio 2003). The population in the near-coastal zone (i.e. within 100 meters elevation and 100 kilometres distance of the coast) in 1990 was calculated at 1.2 billion; 23% of the world's population (Klein *et al.* 2003). Globally, coastal populations are expected to increase rapidly, while coastal settlements are at increased risk to climate change influenced sea level rise. Informal settlements within urban areas of developing country cities are especially vulnerable, as they tend to be built on hazardous sites and to be susceptible to floods, landslides, and other climate-related disasters (Cross, 2001).

Several recent assessments have considered vulnerabilities of rapidly growing and/or large urban areas to climate change. Examples include cities in the developed and developing world such as Hamilton City, New Zealand (Jollands et. al. 2005), London (Holman et. al. 2005; London Climate Change Partnership 2004**),** New York (Rosenzweig and Solecki 2001a and b), Boston (Kirshen et. al. 2006), Mexico City, Krakow (Twardosz 1996), São Paulo, Cochin (ORNL/CUSAT 2003), and Seattle (Office of Seattle Auditor 2005). The case studies have illustrated how larger settlements are important not only in terms of their vulnerabilities to <u>impacts</u> of climate change but also as <u>determinants</u> of climate change (Working Group III; Sanchez-Rodriguez et. al. 2005).

Climate change interacts with and potentially exacerbates ongoing environmental change and environmental pressures in cities (e.g. exposures to flooding, urban heat island conditions, and air pollution). In areas such as the Gulf Coast of the United States, for example, land subsidence is expected to add to apparent sea level rise. For New York City, climate change driven sea level rise will accelerate the inundation of coastal wetlands, threaten vital infrastructure and water supplies, augment summertime energy demand, and affect public health (Rosenzweig and Solecki,2001a; Kinney et. al. 2006; Knowlton *et al.* 2004). Significant costs of coastal and riverine flooding are possible in the Boston metropolitan area (Kirshen *et al.* 2006). These concurrent impacts on human settlements could have further impacts on the local quality of life and economic activity. In addition, for cities that play leading roles in regional or global economies, such as New York, effects could be felt at the national and international scales via disruptions of business activities linked to other places (Solecki and Rosenzweig 2006).

Sea level rise could raise a broad suite of issues. Studies in the New York City metropolitan area have projected that climate change impacts associated with expectations that sea level will rise could reduce the return period of 100-year storm flooding to 19-68 years, on average, by the 2050s, and to 4-60 years by the 2080s (Rosenzweig and Solecki, 2001a), jeopardizing low-lying buildings and transportation systems. Similarly, a study on the climate change impacts in the eastern Caribbean found that coastal infrastructure was vulnerable to sea level rise (Lewsey *et al*, 2004). Due to a long coastline and extensive low-lying coastal areas, projected sea-level rise in Estonia and the Baltic Sea region could endanger natural ecosystems, cover beach areas high in recreational value, and cause environmental contamination. For example, the greatest threat to the environment of the Gulf of Finland and the whole Baltic Sea is the dumping site of the former uranium enrichment plant in Sillamäe, situated very close to the coastline and potentially disturbed during storms, which may increase in their intensity in the coming decades (Kont *et al*, 2003).

Another body of evidence suggests that human settlements, coastal and otherwise, are affected by climate change related shifts in precipitation. Concerns include increased flooding potential from more sizeable rain events (Shepard *et al.* 2002). Conversely, any change in climate that reduces precipitation and impairs underground water resource replenishment would be a very serious concern for some human settlements, particularly in arid and semi-arid areas (Rhode 1999), in settlements with human-induced water scarcity (Romero Lankao 2006), and in regions dependent on snowpack and glaciers (Los Andes, Chapter 13).

A wider range of health implications of climate change also can affect settlements. For example, besides heat stress and respiratory distress from air pollution, changes in temperature, precipitation, and/or humidity affect environments for water-borne and vector-related diseases. Projections of climate change impacts in New York City show significant increases in respiratory-related health attacks and hospitalization (Rosenzweig and Solecki 2001a; see Chapter 4).

With growing urbanization and development of modern industry, air quality and haze have become more salient issues in many urban areas. Many cities in the world, especially in developing countries, are experiencing air pollution problems, such as Buenos Aires, London, Chongqing, Lanzhou, Mexico City, and São Paulo. The problems of London and Chongqing are mainly due to the air pollutants and fog, Lanzhou and Mexico City are mainly due to air pollution that cannot be dispersed because they are surrounded by mountains, and Buenos Aires and São Paulo result from extensive heavy industry pollution. How climate change might interact with these problems is not clear as a general rule, although temperature increases would be expected to aggravate ozone pollution in many cities (e.g., Molina *et al.* 2005, Kinney *et al.* 2005).

Another issue is urban heat island (UHI) effects: higher temperatures occur in urban areas relative to outlying rural areas because of diurnal cycles of absorption and later re-radiation of solar energy and (to a much lesser extent) heat generation from physical structures. The causes of UHI are complex and the interaction between atmospheric processes at different scales is complicated (Oke 1982). The urban heat island effect can influence the climatic comfort of the urban population, affecting their health, their labour productivity, and their leisure activities; there are also economic effects, such as the additional cost of climate control within buildings, and environmental effects, such as the formation of smog in cities and the degradation of green spaces. Even such small coastal towns as Aveiro in Portugal have been shown to create a heat island, the intensity (the difference between night-time minimum temperatures in urban vs. rural areas) of which can reach 7.5 degrees C. (Pinho and Orgaz 2000). Rosenzweig *et al.* (2005) found that climate change based on down-scaled GCM projections would exacerbate the heat island condition by increasing the baseline temperatures and reducing the local wind speeds.

In sum, settlements are vulnerable to direct impacts which can be exacerbated by climate change (e.g., severe storms and associated coastal and riverine flooding, especially when combined with sea level rise, snow storms and freezes, and fire). Nevertheless, the ultimate importance of climate change impacts for human settlements lies in interactions with *other* stresses on settlements, such as scarcity of water or governance structures that are inadequate even in the absence of climate change (Feng *et al.* 2006; Solecki and Rosenzweig 2006). Such phenomena as unmet resource requirements, congestion, poverty, economic inequity, social tensions, and insecurity can be serious enough in some settlements that any significant additional stress could be the trigger for serious disruptive events and impacts. Other stresses may include institutional and jurisdictional fragmentation, limited revenue streams for public-sector roles, and fixed and inflexible patterns of land use. These types of stress do not take the same form in every city and community, nor are they equally severe everywhere, but many of the places where people live across the world are under pressure from some combination of continuing growth, pervasive inequity, jurisdictional fragmentation, fiscal strains, and aging infrastructure. This is especially the case developing countries where climate change mixes in with rapid local environmental change driven by accelerated urbanization and economic development. Climate change becomes one of many changes to be understood and planned for by local managers and decision-makers.

7.4.2.5 Social issues

This section includes vulnerabilities to impacts on society, including political processes which can interact with social stresses in many ways (WBGU 2006). These impacts are likely to vary from place to place and among different social groups, but the greatest concerns are:

a Extreme weather events. Severe storms, floods, and fires become more frequent and/or more intense, urban, peri-urban and rural communities will be severely impacted: lives will be lost, property and infrastructure will be destroyed, industry and services will be disrupted, and economic and managerial resources will be strained. Recent examples include El Niño-related fires in Indonesia, the four major hurricanes hitting Florida within a 44 day-period in 2004, floods in the Mississippi and Red River valleys of the USA, Katrina in New Orleans, and the European heat wave in 2003 (Chapter 14, Kershow and Messon 2005).

b Second and third order impacts. Human activities are unique among climate change impact concerns in the importance of indirect impacts, as mentioned in Section 7.2 above. For instance, climate change can influence the economic competitiveness of other regions of the country and the world, which affects local job creation and population migration. One indirect impact of particular concern in some areas is the effects on city life, local economies, and family budgets of climate change mitigation initiatives (e.g., Rose and Zhang 2004; Rose and Oladosu 2002).

c Increased migration/circulation. Migration, usually temporary and often from rural to urban areas, is a common response to calamities such as floods and famines (Mortimore 1989), and large numbers of displaced people are a likely consequence of extreme events. Their numbers will increase, and so will the likelihood of their migration becoming permanent, if such events increase in frequency (Box 7.3).

d Especially impacted segments of the population. Impacts of climate change are likely to be felt most acutely by certain segments of the population, especially the poor, the elderly, the very young, the powerless, and recent immigrants, particularly if they are linguistically isolated -- those most dependent on public support. Impacts will also differ according to gender (Klinenberg 2002, Cannon 2002, Box 7.4)

e Increased vulnerability of governance systems. As in the cases of insurance and infrastructure above (7.4.2), where climate change affects needs for social services – increasing or decreasing them – it can impact government institutional capacities and resources. Examples include requirements for public health care (Chapter 8), emergency preparedness, land use management, social services to the elderly, public transportation, and even public security where climate-related stresses are associated with social tensions. Where budgets of local or regional governments are affected by increased demands, such effects can lead to calls for either increasing revenue bases or reducing other government expenditures, which implies a vulnerability of governance systems to climate change: not only organizations and social actors but also the mechanisms and processes through which interests are articulated, rights are exercised and conflicts mediated. As sources of stress multiply and magnify in consequence of global climate change, the resilience of already overextended economic, political, and administrative institutions will tend to decrease especially in the most impoverished regions. Whatever happens, it is likely that if things go wrong people will blame "the Government." To avoid such outcomes, governance systems are likely to react to perceptions of growing stresses through regulation and strengthening of emergency management systems (Christie and Hanlon 2001).

f Increased uncertainty/interruptions and opportunity costs. Increased uncertainty is itself an impact, with the potential to undermine decisiveness, private investment and public support for adaptation. Increased frequency or severity of climate-related crises will present serious opportunity costs: i.e., other things that local authorities need to do that are excluded by having to pay the costs of climate change/variability impacts (Freeman and Warner 2001).

The vulnerability of human societies to climate change varies also with economic, social and institutional conditions. This is where socioeconomic diversity within cities, rural settlements, and their productive sectors, linkage systems, and infrastructure comes to the fore. Urban neighbourhoods that are well served by health facilities and public utilities or have additional economic and technical resources are better equipped to deal with weather extremes than poor and informal settlement areas, and their actions can affect the poor as well (Reiter *et al.* 2004). Relatively wealthy market-oriented farmers can afford more expensive deep well pumps. In coastal settlements, large-scale fishing entrepreneurs can afford to relocate or diversify. By contrast, poverty raises serious issues for impacts and responses, including the following:

a. The poor cannot afford adaptation mechanisms such as air conditioning, heating, or climate-risk insurance (which is unavailable or significantly restricted in most developing countries). The poor depend on water, energy, transportation and other public infrastructures, which when affected by climate change related disasters are not immediately replaced (Freeman and Warner 2001). Instead, they base their responses on diversification of their livelihoods or on remittances and other social assets (Klinenberg 2002, Wolmer and Scoones ed. 2003). In many countries, recent reductions in services and support from central governments have reduced the resources available to provide adequate preparedness and protection (see chapter 17). This does not necessarily mean that "the poor are lost;" they have other coping mechanisms (see Section 7.6 below), but climate change might go beyond what traditional coping mechanisms can handle (Wolmer and Scoones ed. 2003).

b. Especially in developing countries, the poor tend to live in informal settlements, with irregular land tenure and self-built ramshackle houses, lacking adequate water, drainage and other public services and often situated in risk-prone areas (OECD 2004, Romero Lankao *et al.* 2005). For these reasons, they are the most likely to be killed or harmed by extreme weather-related events. Over the past decade, disasters in countries with a high human development index killed an average of 44 people per event, while disasters in countries with a low human development index killed an average of 300 people each (Bigio 2003).

Box 7.3: Environmental Migration

Disaggregating the causes of migration is highly problematic, not least since individual migrants may have multiple motivations, and be displaced by multiple factors (Black, 2001). For example, studies of displacement within Bangladesh, and to neighbouring India, have drawn obvious links to increased flood hazard as a result of climate change, but such migration also needs to be placed in the context of changing economic opportunities in the two countries and in the emerging megacity of Dhaka, the encouragement of migration by some politicians in India, rising aspirations of the rural poor in Bangladesh, and rules on land inheritance and an ongoing process of land alienation in Bangladesh (Abrar and Azad, 2004).

Estimates of the number of people who may become environmental migrants are at best guesswork, and at worst, dangerous, since (a) migrations in areas impacted by climate change are not one-way and permanent, but multi-directional and often temporary or episodic; (b) the reasons for migration are often multiple and complex, and do not relate straightforwardly to climate variability and change; (c) In many cases migration is a longstanding response to *seasonal* variability in environmental conditions. It also represents a strategy to *accumulate* wealth or to seek a route out of poverty, a strategy with benefits for both the receiving and original country or region; (c) there are few reliable censuses or surveys in many key parts of the world on which to base such estimates (e.g. Africa); and (d) there is a lack of agreement on what an environmental migrant is anyway (Unruh *et al.* 2004).

An argument is also made that rising ethnic conflicts can be linked to competition over natural resources that are increasingly scarce as a result of climate change, but many other intervening and contributing causes of inter- and intra-group conflict need to be taken into account. For example, major environmentally-influenced conflicts in Africa have more to do with relative abundance of resources – oil, diamonds, cobalt, and gold for example, than with scarcity (Fairhead, 2004). This allows little confidence in the prediction of such conflicts as a result of climate change.

Vulnerabilities to impacts of climate variability and change are related not only to poverty but to geographical location as well. For instance, indigenous societies in polar regions and settlements close to tropical glaciers in the Andes are already experiencing threats to their traditional livelihoods (Chapters 13 and 15). Indigenous societies in the Arctic are facing a loss of traditional food sources and related ways of life, posing serious challenges to the survival of their cultures (ACIA, 2004). Such other locations as low-lying island nations are also threatened (Chapter 16). Increased temperatures in mountain areas and in temperate zones needing space-heating during the winter may result in energy cost savings for their poor settlers. On the other hand, areas relying on electric fans or air conditioning may see increased pressures on household budgets as average temperatures rise.

7.4.3 Key vulnerabilities

As a general statement about a wide diversity of circumstances, the major climate change vulnerabilities of industries, settlements, and societies are:

1. vulnerabilities to especially extreme weather and climate events, particularly if abrupt major climate change should occur
2. vulnerabilities to climate change as one aspect of a larger multi-stress context: relationships between climate change and thresholds of stress in other regards

3. vulnerabilities of particular geographical areas: coastal and riverine areas vulnerable to flooding and continental locations where changes have particular impacts on human livelihoods; the most vulnerable are likely to be populations in areas where subsistence is at the margin of viability or near boundaries between major ecological zones, such as tundra thawing in polar regions and shifts in ecosystem boundaries along the margins of the Sahel
4. vulnerabilities of particular populations: those with limited resources for coping with and adapting to climate change impacts
5. vulnerabilities of particular economic sectors sensitive to climate conditions, such as tourism, risk financing, and agro-industry.

All of these concerns can be linked both with direct effects and indirect effects through inter-connections and linkages, both between systems (such as flooding and health) and between locations.

Most key vulnerabilities are related to (a) climate phenomena that exceed thresholds for adaptation, i.e., extreme weather events and/or abrupt climate change, often related to the magnitude and rate of climate change (see Box 7.4: Hurricane Katrina), and (b) limited access to resources (financial, human, institutional) to cope, rooted in issues of development context. Most key vulnerabilities are relatively localized, in terms of geographic location, sectoral focus, and segments of the population, although literatures to support such detailed findings about potential impacts are very limited. Based on the information summarized in the sections above (Table 7.4), key vulnerabilities of industry, settlement, and society include the following, each characterized by a level of confidence:

- Interactions between climate change and global urbanization, especially in developing countries, which is often focused in vulnerable areas (e.g., coastal), especially when mega-cities and rapidly growing mid-sized cities approach possible thresholds of sustainability (VERY HIGH CONFIDENCE).
- Interactions between climate change and global economic growth: relevant stresses are linked not only to impacts of climate change on such things as resource supply and waste management but also to impacts of climate change <u>response</u> policies, which could affect development paths by requiring higher cost fuel choices (HIGH CONFIDENCE).
- Increasingly strong and complex global linkages, which cause climate change to cascade through expanding series of interactions to produce a variety of indirect effects, some of which may be unanticipated, especially as the globalized economy becomes less resilient and more interdependent – vulnerabilities include interregional trade patterns and migration patterns (VERY HIGH CONFIDENCE).
- Fixed physical infrastructures that are important in meeting human needs: infrastructures susceptible to damage from extreme weather events or sea level rise and/or infrastructures already close to being inadequate, where an additional source of stress could push the system over a threshold of failure (HIGH CONFIDENCE).
- Interactions with governmental and social/cultural structures that are already stressed in some places by other kinds of change, such as population pressure and limited economic resources, and which could become no longer viable when climate change is added as a further stress (MEDIUM CONFIDENCE).

In all of these cases, the valuation of vulnerabilities depends considerably on the development context. For instance, vulnerabilities in more developed areas are often focused on physical assets and infrastructures and their economic value and replacement costs, along with linkages to global markets, while vulnerabilities in less developed areas are often focused on human populations and institutions, which need different metrics for valuation.

Although it would be very useful to be able to associate such general vulnerabilities with particular impact criteria, climate change scenarios, and/or time frames, the current knowledge base does not support such specificity with an adequate level of confidence.

Box 7.4: Vulnerabilities to Extreme Weather Events In Mega-Deltas in a Context of Multiple Stresses: The Case of Hurricane Katrina

It is possible to say with a high level of confidence that sustainable development in some densely populated mega-deltas of the world will be challenged by climate change, not only in developing countries but in developed countries as well. The experience of the U.S. Gulf Coast with Hurricane Katrina in 2005 is a dramatic example of complex interactions between a major weather event – of a type expected to become more intense with climate change – and a variety of demographic, social, and economic processes and stresses.

In 2005, New Orleans was a city of about half a million in population, located in the Mississippi River delta in the Southeastern United States. Its area is subject not only to seasonal storms (Emanuel 2005) but also to land subsidence in excess of 10 mm/yr (IPET 2006). Embankments of the river have resulted in the loss of coastal wetlands that tend to reduce coastal flood heights, while urban development has increased land use and settlement in areas vulnerable to flooding. Meanwhile, a number of studies of the protective levee system indicated growing vulnerabilities to severe storms, but actions were not taken to assure protection.

In late August 2005, Hurricane Katrina – which had been a Category 5 storm but weakened to Category 3 before landfall – moved onto the Louisiana and Mississippi coast with waves of 8.5 m above sea level. 70 to 80 % of New Orleans flooded, with 55 % of the city's properties inundated by more than 1.2 m and maximum flood depths up to 6 m. 1101 people died in Louisiana, nearly all related to flooding, concentrated among the poor and elderly.

Across the whole region, there have been 1.75 million private insurance claims, costing in excess of $40Bn (Hartwig, 2006), while total economic costs are projected to be significantly in excess of $100Bn. Katrina has also exhausted the federally backed National Flood Insurance Program (Hunter, 2006), which has had to borrow $23Bn from the Government to fund the Katrina residential flood claims. In New Orleans alone, while flooding of residential structures caused $8-$10Bn in losses, $3-6Bn was uninsured – with 34,000-35,000 of the flooded homes carrying no flood insurance, including many that were not in a designated flood risk zone (Hartwig, 2006).

Other areas of the United States have been affected as well. For instance, areas that hosted evacuees had to provide shelter and schooling, storm damage in the Gulf region raised highway vehicle fuel prices nationwide, reconstruction costs have drove up the cost of construction throughout the eastern US, and federal government funding for many programs was reduced because of commitments to provide financial support for hurricane recovery.

Table 7.4: *Selected examples of current and projected climate change impacts on human settlements, energy and industry, and their interaction with other processes*

Climate Driven Phenomena	Evidence for Current Impact/ Vulnerability	Other Processes/ Stresses	Projected Future Impact/ Vulnerability	Zones, Groups Affected
a) Changes in extremes				
Major storms, in coastal areas combined with SLR	Population dead, injured, displaced; damages to settlements, economic activities, transportation systems; impacts on tourism; demands for insurance coverage (7.4.2.2; 7.4.3; Box 7.5; 7.5)	Population density, land uses in vulnerable areas; institutional capacities	Increased vulnerability in storm-prone coastal areas; possible effects settlements, health, tourism, economic and transportation systems	Coastal areas, settlements, and activities; regions and populations with limited capacities and resources; fixed infrastructures; insurance sector
Riverine floods	Similar to coastal storms, especially vulnerabilities of settlements and transportation systems (see regional chapters)	Similar to coastal storms	Similar to coastal storms	Similar to coastal storms
Heat or cold waves	Effects on human health, social stability, energy requirements (7.2; Box 7.2; 7.4.2.2)	Limited capacities in some areas for internal temperature control; demographic and social contexts; institutional capacities	Increased vulnerabilities in some regions and populations; health effects; energy requirements	Mid-latitude areas; elderly, very young, and/or very poor populations
Drought	Reduced water availability in dry areas (7.4.2.3; environmental migration (7.4.2.5)	Land uses; resources and capacities for alternative water supply	Water resource challenges in affected areas; shifts in locations of population and economic activities	Affected regions; poor regions and populations; settlements and societies in dry areas
b) Changes in means				
Temperature	Effects on energy demands and costs; on urban air quality; on tourism; on retail consumption; and on societies/livelihoods: e.g., traditional societies in the Arctic (7.4.2.1, 7.4.2.2, 7.4.2.4, 7.4.2.5)	Demographic and economic changes, land use changes, sustainable development paths, technological change, institutional capacities	Greater vulnerabilities away from coasts; diverse vulnerabilities in particular locations and sectors, both to temperature increase and to its association with storms and other extreme events	Very diverse, but greater vulnerabilities in places and populations with more limited capacities and resources for adaptation
Precipitation	Effects on water infrastructures, tourism,	Processes related to	Depending on the region,	Poor regions and populations

	energy supplies; also see flooding above (7.4.2.1, 7.4.2.2, 7.4.2.3); special concerns include reduced snow cover as an issue for tourism and seasonal water supply	water demand and management	vulnerabilities in some areas to effects of precipitation increases (e.g., flooding, but could be positive) and in some areas to decreases (see drought above)	
Saline intrusion	Effects on water infrastructures (7.4.2.3)	Trends in groundwater withdrawal	Increased vulnerabilities in coastal areas	Low-lying coastal areas, especially those with limited capacities and resources
Sea level rise	Effects on coastal land uses: greater exposure to flooding, water logging; effects on water infrastructures (7.4.2.3; 7.4.2.4)	Trends in coastal settlement and land uses	Long-term increases in vulnerabilities of low-lying coastal areas	Same as above
c) Abrupt climate change	Analyses of potentials	Demographic, economic, and technological changes; institutional developments	Possible significant effects on most places and populations in the world, at least for a limited time	Most zones and groups

Note: In the TOD, typeface will indicate source of rating: a) bold will indicate direct evidence or study, b) italics will indicate direct inference from similar impacts, and c) plain text will indicate logical conclusion from settlement type, but cannot be directly corroborated.

7.5 Costs and other socioeconomic issues

Costs or benefits of climate change-related impacts on industry, settlements, and society are difficult to estimate. Reasons include the facts that effects to date that are clearly attributable to climate change are limited, most of the relatively small number of estimates of macroeconomic costs of climate change refer to total economies rather than to the more specific subject matter of this chapter, generalizing from scattered cases that are not necessarily representative of the global portfolio of situations is risky, historical experience is of limited value when the potentially impacted systems are themselves changing (e.g., with global economic restructuring and development and technological change), and many types of costs – especially to society – are poorly captured by monetary metrics. In many cases, the best guides to projecting possible costs of climate change are costs associated with recent extreme weather events of types projected to increase in intensity and/or frequency, although this is only one kind of possible impact.

Estimates of aggregate macroeconomic costs of climate change at a global scale (e.g., IPCC 2001 – WG II – Ch. 19) are not directly useful for this chapter, other than generally illustrating that because many locations, industrial sectors, and settlements are not highly vulnerable, total monetary impacts at that scale might not be large in proportion to the global economy. As section 7.4 indicates, however, vulnerabilities of particular localities and/or sectors and/or societies could be considerable. A salient example is climate change impacts already being experienced by societies and settlements in the Arctic, which include destabilized buildings, roads, airports, and industrial facilities, requiring substantial rebuilding, maintenance, and investments (ACIA 2004). An impact assessment in the UK projected that annual weather-related damages to land uses and properties could increase by 3 to 9 times by the 2080s (Harman *et al.* 2005).

More generally, as one specific aspect of vulnerabilities to climate change, possible economic costs of sea-level rise have been estimated, since exposures of seacoast phenomena to a specified scenario can be analyzed for costs of the change vs. costs of protecting against the change; and effects of direct costs in coastal areas can be projected for other parts of a regional or national economy (e.g., Bosello *et al.* 2004; Tol *et al.* 2006; Nicholls and Tol 2006). Generally, these studies indicate that the costs of full protection are greater than the costs of losing land to sea-level rise, although they do not estimate non-monetary costs of social dislocations.

Recent climate-related extreme weather events have been associated with cost estimates for countries and economic sectors; and trends in these costs have been examined, especially by the reinsurance industry (e.g., Munich Re 2005; also see Chapter 1). According to these estimates, an increase in the intensity and/or frequency of weather-based natural disasters, such as hurricanes, floods, or droughts, could be associated with very large costs to targeted regions in terms of economic losses and losses of life and disruptions of livelihoods, depending on such variables as the level of social and economic development, the economic value of property and infrastructure affected, and capacities of local institutions to cope with the resulting stresses. Estimates of impacts on a relatively small country's GDP in the year of the event range from 4 to 6% (Mozambique flooding: Cairncross and Alvarinho 2005) to 3% (El Niño in Central America) to 7% (Hurricane Mitch in Honduras: Figure 7.3). Even though these macroeconomic impacts appear relatively minor, countries facing an emergency found it necessary to incur increased public spending and obtain significant support from the international donor community in order to meet needs of affected populations. This increased fiscal imbalances and current account external deficits in many countries, and there were a number of cases of environmental migration.

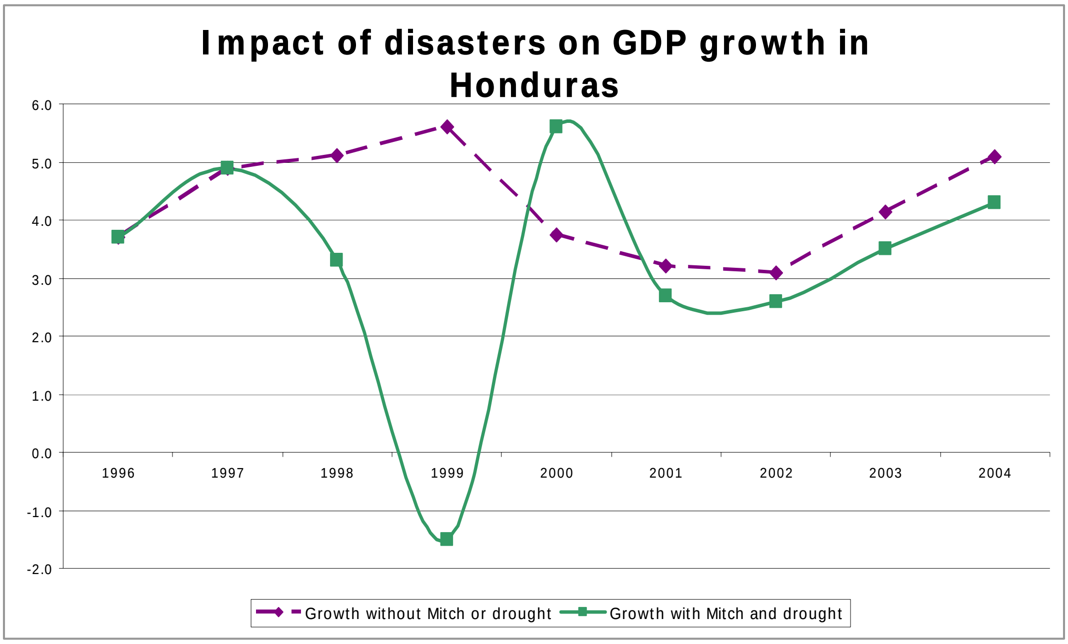

Figure 7.3: *Economic Impact of Hurricane Mitch in Honduras*

For specific regions and locales, of course, the impact on a local economy can be considerably greater (see Box: Hurricane Katrina). Estimates suggest that impacts can exceed gross domestic product and gross capital formation in percentages that vary from less than ten percent in larger, more developed and diversified impacted regions to more than 50% in less developed, less diversified, more natural resource dependent regions (Zapata-Marti 2005).

It has seems likely that if extreme weather events become more intense and/or more frequent with climate change, GDP growth over time could be adversely affected unless investments are made in adaptation and resilience.

Research has also considered costs of extreme weather-related events on certain sectors of interest, especially water supply infrastructures. For instance, if reduced precipitation due to climate change were to result in an interruption of urban water supplies, effects could include disruptions of industrial activity as well as hardships for population, especially the poor, who have the least options for alternative supplies (Cairncross and Kinnear, 1992). The cost of extending pipelines is considerable, especially if it means that water treatment works also have to be relocated. As a rough working rule, the cost of construction of the abstraction and treatment works and the pumping main for an urban settlement's water supply is about half the cost of the entire system. Bearing in mind that a city water utility, obliged to move the abstraction point upstream to avoid saline intrusion, will usually choose to do so at a time when capacity needs to be expanded anyway, the marginal cost of the longer pipeline can more reasonably be assumed to be of the order of 10% of the total.

The cost of flood damage is often even more considerable. For example, the catastrophic flooding of southern Mozambique in 2000 caused damage to water supplies which (according to the World Bank, 2000) cost $13.4 million to repair, or roughly $50 per person, of the same order as the cost of providing them with water supplies in the first place. Part of the explanation is that the damaged water supplies also served people whose homes were not directly affected by the flooding; this can be expected to occur in other floods. Nicholls (2004) has estimated that some 10 million people are affected annually by coastal flooding, and that this number is likely to increase until 2020 under all four SRES scenarios, largely because of the increase in the exposed population.

A particular concern for industry, settlements, and society is the prospect of abrupt climate change, which could exceed coping mechanisms in many settlements and societies (National Research Council 2002). In such a case, fixed infrastructures are especially vulnerable, although the research base is very limited.

The existing literatures are, in these ways, useful in considering possible costs of climate change for industry, settlement, and society; but they are not sufficient to estimate costs globally or regionally associated with any specific scenario of climate change. All that can be said at the present time is that economic costs of extreme weather events at a large national or large regional scale, estimated as a percent of gross product in the year of the event, are unlikely to represent more than several percent of the value of the total economy, except for possible abrupt changes (HIGH CONFIDENCE), while economic and other human costs of extreme event impacts for some economic sectors in some smaller locations, especially in developing countries, could in the short run exceed 25 percent of the gross product in that year (HIGH CONFIDENCE). To the degree that these events increase in intensity and/or frequency, they will represent significant costs due to climate change.

7.6 Adaptation: practices, options, and constraints

Challenges to adapt to observed and expected variations and changes in environmental conditions have been a part of every phase of human history, and human societies have generally been highly adaptable (Ausubel and Langford 1997). Adaptations may be anticipatory or reactive, self-induced and decentralized or dependent on centrally initiated policy changes and social collaboration, gradual and evolutionary or rooted in abrupt changes in settlement patterns or economic activity. Historically, adaptations to climate change have probably been most salient in coastal areas vulnerable to storms and flooding, such as the Netherlands, and in arid areas needing water supplies; but human settlements and activities exist in the most extreme environments on earth, which shows that the capacity to adapt to known conditions, given economic and human resources and access to knowledge, is considerable.

Adaptation strategies vary widely by the exposure of a place or sector to dimensions of climate change, its sensitivity to such changes, and its capacities to cope with the changes (Chapter 17). Some of the strategies are multisectoral, such as improving climate and weather forecasting at a local scale, emergency preparedness, and public education. One example of cross-cutting adaptation is improving information and institutions for emergency preparedness. Systematic disaster preparedness at community level has helped reduce death tolls; for instance, new warning systems and evacuation procedures in Andhra Pradesh, India, reduced deaths from coastal tropical cyclones by 90 percent, comparing 1979 with 1977 (Winchester 2000). The effectiveness of such systems in reaching marginal populations and their responses to such warnings, however, is uneven; and the timing of decisions to adapt affects the likely benefits.

Other strategies are focused on a sector, such as water, agriculture, forests, and health (see Chapters 3, 4, 5, and 8). Some are geographically focused, such as coastal area and floodplain adaptation, which can involve such initiatives as changing land uses in highly vulnerable areas and protecting critical areas; in fact, adaptation tends very often to be context-specific, working within larger market and policy structures (Adger, *et al.* 2005), although it generally takes place within the larger context of globalization (Benson and Clay 2003).

There is a considerable literature on adaptations to climate *variation* and vulnerabilities to *extreme events*, especially in developed countries; but research on potentials and costs of adaptation to *climate change* is still in an early stage (Chapter 17). One challenge is that it is still difficult to project changes in particular places and sectors with much precision, whether by downscaling global climate models or by extrapolating from past experience with climate variation. Uncertainty about the distribution and timing of climate change impacts at the local level makes judgments about the scale and timing of adaptation actions very difficult. Where there are co-benefits between climate change adaptation and other economic or social objectives, there will be reasons for early action. In other cases, limits on predictability tend to delay adaptation (Wright and Erickson 2003). In addition, there is little scientific basis as yet for assessing possible limits of adaptation, especially differences among locations and systems. In particular, the knowledge base about costs of adaptation is less well-developed than the knowledge base about possible adaptation benefits. At least in some cases, costs might exceed actual benefits.

7.6.1 Industry

The extent to which potential vulnerabilities of industry are significant economically will depend to a large extent on the flexibility of business and on its capacity to adapt. In general, those industries with longer-lived capital assets (e.g., energy), fixed or weather-dependent resources (mining, food, and agriculture), and extended supply chains (e.g., the retail-distribution industry) are likely to be more vulnerable to climate change impacts. But many of these industries, especially in the industrialised world, are likely to have the technological and economic resources necessary both to recover from the impacts of extreme events (partly by sharing and spreading risk or by moving to safer locations), and to adapt over the longer term. It is also clear that many other economic and social factors will play a more important in influencing industrial development than climate change. For many businesses, climate risk management can be integrated into overall business strategy and operations where it will be regarded as one among many issues that demand attention, to the degree that such adaptation is supported by investors and shareholders.

There is now considerable evidence emerging in Europe, North America and Japan that the construction and transportation sectors are paying attention to climate change impacts and the need for adaptation (Liso *et al.* 2003, Shimoda 2003, Salagnac 2004). As one example, the $1 billion 12.9 kilometre Confederation Bridge between New Brunswick and Prince Edward Island, which opened in 1997, was built one metre higher to accommodate anticipated sea-level rise over its 100-year lifespan (McKenzie and Parlee 2003). A range of technical advice is now available to planners, architects and engineers on climate impacts risk assessment (UKCIP 2002, Willows and Connell 2003), including specialised advice on options for responding to these risks (Lancaster *et al.* 2004, Vivien *et al.* 2005). A few early estimates of possible costs of adaptation measures are beginning to be available; for instance, O'Connell and Hargreaves (2004) show that measures to reduce wind damage, flood risk and indoor heat would add about 5 percent to the cost of a typical new house in New Zealand.

Business adaptations can take a wide variety of forms. They may include changes in business processes, technologies or business models (Hertin *et al*, 2003), or changes in the location of activities. Many of these adaptations represent incremental adjustments to current business activities (Berkhout *et al.* forthcoming). For instance, many techniques already exist for adapting buildings in response to greater risks of ground movement, higher temperatures and driving rain. For more structural adaptations – such as choice of location for industrial facilities – planning guidance, government policy, and risk management by insurers will play major roles.

Awareness, capabilities and access to resources that facilitate adaptation are likely to be much less widely available in less developed contexts, where industrial production often takes place in areas vulnerable to flooding, coastal erosion and land slips, and is more likely to be tied to natural resources affected by changing climates. Potentials for adaptation to climate change in informal industry in developing countries depend largely on the context: e.g., the impacts involved, the sensitivity of the industrial activity to those impacts, and the resources available for coping. Examples of adaptive strategies could include relocating away from risk-prone locations, diversifying productive activities, and reducing stresses associated with other operating conditions to add general resiliency. Informal industry employs minimal capital and few fixed assets, so that it usually adapts relatively easily to gradual changes. But most adaptations that are substantial may call for an awareness of threats and alternatives that go beyond historical experience, a willingness to depart from traditional activity patterns, and access to financial resources not normally available to some small producers.

The energy sector can adapt to climate change vulnerabilities and impacts by anticipating possible impacts and taking steps to increase its resilience, e.g., by diversifying energy supply sources, expanding its linkages with other regions, and investing in technological change to further expand its portfolio of options. This sector has impressive investment resources, and it has the potential to be a leader in industrial adaptation initiatives. On the other hand, many energy sector strategies involve high capital costs, and social acceptance of significantly higher energy prices may be limited.

7.6.2 Services

Concerns about vulnerabilities and impacts for services are likewise concentrated on sectors especially sensitive to climate variation, such as recreation and tourism, and adaptations are likely also be associated with changes in costs/prices, applications of technology, and attention to risk financing. For instance, wholesale and retail trade are likely to adapt by increasing or reducing space cooling and/or heating, by changing storage and distribution systems to reduce vulnerabilities, and by changing the consumer goods and services offered in particular locations. Some of these adaptations, although by no means all of them, could increase prices of goods and services to consumers.

The short time-scales at which most commercial services operate allow great flexibility for adapting to climate change. Within the retail industry, it is likely that commerce will capitalise on long-term trends in consumer behaviour and lifestyle, relating to climate change through an expansion of markets for cooling equipment and, facilities and goods for outdoor recreation in temperate climates. large injections of capital may be required to relocate commercial premises from low-lying areas vulnerable to flooding. In addition, technological investment will be required from reduce carbon emissions while maintaining competitive prowess in the global market. The agro-industry may have limited opportunities to adapt at a local level, as the source regions for natural raw materials such as food products, timber, and seafood shift in response to changing climate patterns. The most vulnerable are communities (particularly in developing countries) whose economy is based on the production and distribution of a restricted range of climate-sensitive commodities. For these communities, economic diversification should be a key response to reduce vulnerability

The tourism sector may in some cases be able to adapt to long term trends in climate change, such as increasing temperatures, at a cost, for instance by investing in snow-making equipment (see Ch 14), beach enhancement (see Ch 6), or additional air-conditioning. The sustainability of some adaptation processes may be questionable: air conditioning because of its energy use, snowmaking for its pressure on water resources or its costs (O’Brien *et al.* 2004). However, climate change is not likely to be linear, and the frequency and intensity of extreme climatic events, which affect not only the reality of risks, but also the subjective risk-perception of tourists, might become a far greater problem for the tourist industry. There are three categories of adaptation processes: technological, managerial, and behavioural. While tourism providers tend to focus on the first two (preserving tourism assets, diversifying supply), tourists might rather change behaviour: they might visit new, suitable locations (for example snow-safe ski resorts at higher altitudes or in other regions) or they might travel during other periods of the year (for example, they might visit a site in spring instead of summer to avoid extreme temperatures). Adaptive capacities and strategies are likely to vary among stakeholders. For example, large tour operators should be able to adapt to changes in tourist destinations, as they are familiar with strategic planning, do not own the infrastructures and can, to some extent, shape demand through marketing.

Perhaps of even greater importance is the role of mobility in future tourism. Increasing prices for fuel and the need to reduce emissions might have substantial effects on transport availability and costs. For instance, the price of air transport, now the means of transport of 42% of all international tourists, is expected to rise in stabilization scenarios (Gössling and Hall 2005). This might call for adaptation in terms of leisure-lifestyles, such as the substitution of long-distance travel by vacationing at home or nearby (Peeters 2003, Dubois and Ceron 2005).

It also seems likely that tourism based on natural environments will see the most substantial changes due to climate change, including changes in economic costs (Gossling and Hall 2005) and changes in travel flows. Tropical island nations and low-lying coastal areas may be especially vulnerable, as they might be affected by sea-level rise, changes in storm tracks and intensities (see Chapter 16), changes in perceived climate-related risks, and changes in transport costs, all resulting in concomitant detrimental effects for their often tourism-based economies.

In any of these cases, the implications are most notable for areas in which tourism represents a relatively large share of the local or regional economy, and these are areas where adaptation might represent a relatively significant need and a relatively significant cost.

The insurance sector has an important role to play in adaptation. Where new risks are emerging, or known risks are increasing, new insurance coverages can be designed to help spread losses. Examples include the creation of weather derivatives, crop insurance, and expanded property insurance coverage. Insurance is also a principal agent of adaptation through education and incentives for risk reduction strategies, including better building codes and flood prevention schemes.

Generally, it is recognized that 'ex-ante' (before the fact) funding mechanisms in the form of insurance should be more beneficial for the affected community and the whole country's economy than the ex-post mechanism (after the fact) by means of credit, government subsidies or private donations. Only the ex-ante approach offers the potential to influence the level of risk, through linking insurance prices and conditions with government policy on hazard mitigation, implementation, and supervision of building codes etc, thus reducing a country's financial vulnerability and giving improved prospects for investment & economic growth (Gurenko, 2004). However, in developing countries there are questions about the viability of such approaches, concerning who in a poor country is able to afford an ex-ante premium and how real reductions in risk can be achieved in a society with relatively low risk literacy (Linnerooth Bayer *et al.* 2005).

In the developed world, the risk-bearing sector is diversified, including banks, government-backed insurance systems and disaster funds, and individuals. In developing and newly developed countries, insurance coverage is lower (Enz 2000) as wealth protection that typically lags a generation behind wealth accumulation. In developing countries (as highlighted by events such as 2005 Hurricane Stan in Mexico and Guatemala, or 1998 Hurricane Mitch in Honduras) individuals bear the majority of the risk and manage it through the solidarity of family and other networks, including via remittances, if at all. However once development is underway, insurance typically expands faster than GDP growth, with life insurance leading property insurance. With this in mind there has been a focus on promoting 'micro-insurance' to reduce people's financial vulnerability when linked with the broader agenda of risk reduction (ProVention Consortium 2004) (Abels and Bullen 2005).

Besides supporting adaptation, the insurance industry itself may need to adapt to stay healthy. The main threat is a combination of very high loss events in a short time period (as almost happened in September 2005 with Hurricane Rita appearing to be heading for the city of Houston after Hurricane Katrina had hit New Orleans). Trends that might contribute to this robustness include better risk management, greater diversification, better risk and capital auditing, greater integration of insurance with other financial services, and improved tools to transfer risks out of the insurance market (European Environment Agency 2004). Extreme loss events, traditionally the domain of a retrocession market (insuring reinsurers), are increasingly passing out of the insurance market and into the far larger capital markets through catastrophe risk securitizations, industry loss warranties, and the direct and indirect participation of hedge funds.

The key vulnerability of the current system of risk-bearing concerns the non-availability or withdrawal of private insurance cover, in particular related to flood risk. However the threat of withdrawal can itself be a spur for encouraging adaptation. Following the October-November 2000 floods in England and Wales the Association of British Insurers negotiated an increased allocation of government expenditure on flood defences and a stakeholder role in decisions around future development in floodplains, threatening to withdraw flood insurance from locations at greatest risk (Association of British Insurers 2004). With expectations for rising levels of flood risk in developed countries, political pressures demand that if private insurance is withdrawn, state-backed alternatives should be created leading to increased liabilities for governments. In the northern Bahaman islands of Abaco and Grand Bahama (hit by three major hurricanes between 1999 and 2004), flood insurance became withdrawn for some areas, and without any state-backed alternative houses were becoming abandoned as their value collapsed **(**Woon and Rose 2004**).** Meanwhile, builders have begun to construct new houses on concrete stilts, bringing some properties in the coastal floodplain back into the domain of insurability. Similar outcomes can be expected in other coastal regions affected by increasing flood risk.

7.6.3 Utilities/infrastructure

The most general form of adaptation by infrastructures vulnerable to impacts of climate change is investment in increased resilience, for instance in new sources of water supply for urban areas. Most fields of infrastructure management -- including water, sanitation, transportation, and energy management – incorporate vulnerabilities to changing trends of supply and demand and risks of disturbances in their normal planning. Resilience may be defined as the ability of a system to respond to external pressures without losing actual or potential functions (Klein *et al.* 1998), the probability of recovery from a failure once a failure has occurred (Vogel *et al.* 1999), the ability of a system to return to its normal status after external changes exceed the norm of natural fluctuations (Vilcheck 1998), or how quickly a system is able to recover from a disturbance (Maier 2001).

In a situation where climate change -- observed or projected -- indicates needs for different patterns or priorities in infrastructure planning and investment, common strategies are likely to include increases in reserve margins and other types of backup capacity, attention to system designs that allow adaptation and modification without major redesign and that can handle more extreme conditions for operation. In many cases an issue is tradeoffs between capital costs and operating expenditures.

With regard to infrastructure where adaptation requires long lead times, such as water supply, there is evidence that adaptation to climate change is already taking place. An example would be the planning of British water companies mentioned in Section 7.4.2.3.1 above, and undertaken at the behest of the UK Environment Agency (Environment Agency 2004). Another would be the decision taken in 2004 to install a desalination plant to supplement the dwindling flows available for water supply for the city of Perth, Australia (see Chapter 11, box 11.1).

The infrastructure whose adaptation is especially important for the reduction of key vulnerabilities is that installed for flood protection. For example, London (UK) is protected from major flooding by a combination of tidal defences, including the Thames Barrier, and river defences upstream of the Barrier. The current standard for the tidal defences is about a 2000 to 1 chance of flooding in any year or 0.05% risk of flooding, and is anticipated to decline to its original design standard of 1000 to 1 chance, or 0.1% risk of flooding, as sea level rises, by 2030. The defences are being reviewed, in the light of expected climate changes. Preliminary estimates of the cost of providing a 0.1% standard through to the year 2100 show that a major investment in London’s flood defence infrastructure of the order of £4 billion will be required within the next 40 years (London Climate Change Partnership 2004).

7.6.4 Human settlement

For settlements, adaptation strategies include assuring effective governance, increasing resilience of urban physical and linkage infrastructures, changing urban form, reducing heat-island effects, reducing emissions and industry effluents as well as improving waste handling, providing financial mechanisms for increasing resiliency, targeting assistance programs for especially impacted segments of the population and adopting sustainable community development practices (Wilbanks *et al.* 2005). The choice of strategies from among the options depends in part on their relationships with other social and ecological processes (O'Brien and Leichenko, 2000) and the general level of economic development.

The recent case study of London demonstrates that climate change could bring opportunities as well as challenges, depending on socioeconomic conditions, institutional settings, and cultural and consumer values (London Climate Change Partnership 2004). One of the opportunities, especially in growing settlements, is to work toward a more sustainable city and to improve the quality of life for residents. Urban planning can take into account the construction density, the distribution and impact of heat emissions, transportation patterns, and green spaces that can reduce heat island effects.

The intensive use of air conditioning and space cooling in many affluent societies and increasingly in developing countries is an issue GHG mitigation. Currently, dozens of cities, including Shanghai, Chicago, Tokyo, Portland, Oregon, and many German locales, are considering or have implemented GHG mitigation strategies through the use zoning and building code revisions. Several cities in the Arizona, USA region are incorporating concerns regarding urban warming, and space cooling energy demand reductions, into planning codes and practices (Baker *et al.* 2002). Particular considerations include site and building design, urban microclimates (e.g., Assis and Frota 1999; Capeluto *et al.* 2003), the use of vegetation and environmentally sensitive materials (e.g., Gómez *et al.* 2004; Lindsey 1999; Shashua-Bar and Hoffman 2000), the use of passive/active solar housing, and stakeholder participation.

Models have been established to predict the impact of urban thermal property manipulation strategies resulting from albedo and vegetation changes (Akbari *et al.* 1997; Emmanuel 2005). The diurnal air temperature inside urban wooded sites, and the cooling effect of trees on urban streets and courtyards and of groves and lawns has been extensively quantified in Tel-Aviv, Israel (Shashua-Bar and Hoffman, 2002, 2004). For the Los Angeles region, several studies (Taha *et al.* 1997, Taha 1996) projected the effects of increasing citywide albedo levels on mitigating the regional heat island (California's South Coast Air Basin, or SoCAB). A doubling of the surface albedo or a doubling of vegetative cover were each projected to reduce air temperature by approximately 2^{o}C. Moreover, the study area was projected to experience a decrease in ozone concentrations.

Other adaptive responses by settlements to concerns about climate change tend to focus on institutional development, often including improved structures for coordination between individual settlements and other parties, such as enhanced regional water supply planning and infrastructure development (Bulkeley and Betsill 2003; Rosenzweig and Solecki 2001a). Often, settlements exist in a splintered political landscape that makes coherent collaborative adaptation strategies difficult to contemplate. Policy responses are also hampered by the reactive nature of much policymaking, related mainly to current obvious problems, when climate change is viewed as a long-term issue with considerable uncertainty.

One approach for improving the understanding of how settlements may respond to climate change impacts is to consider "analogs" - circumstances in recent history when those settlements have confronted other environmental management challenges (AAG, 2003). In many cases, settlements have acted under the pressure of immediate crises to seek solutions by going beyond their own borders (e.g., Rees, 1992; Tarr, 1996).

7.6.5 Social issues

Adaptation can be implemented at different scales, from individuals to systems, and it is not a uniform concept. Individual adaptations may not produce systemic adaptation, and adaptation at a system level may not benefit all individuals. Indeed, some adaptations will increase the vulnerability of some peoples and places. For example, flood protection upstream may increase discharge downstream and increase flood damages for places that cannot afford the increased protection. As climate change adaptation becomes a widespread need, there is likely to be competition for resources – investment in one place, sector, or risk will reduce the funds available for others, and possibly reduce funding for other social needs. Adaptation is not a capital stock that can be invested in projects, but a process of learning about the changing risks and opportunities, making decisions regarding acceptable risk and returns to investment, and revising strategies as new information becomes available.

Recent scholarship has suggested that identifying determinants of adaptive capacity concerns both the multiscalar nature of adaptation and the diversity of actors and sectors involved in the adaptation process (Adger, Arnell and Tompkins 2005: 79). The complexity of building adaptive capacity in the context of institutional reforms, new trade agreements, and changing relationships between the private and public sectors introduces great challenges to policy making and shapes the roles played by both states and private actors (including business and NGOs) in enhancing the resilience of human and physical systems.

The emergence and dissemination of new governance paradigms at the global level has provided new tools for policy design and implementation (Eakin and Lemos 2006, Mitchell and Romero Lankao 2004) and introduced new and diverse challenges to the national governments by encouraging the devolution of authority to lower (decentralization and privatization) and supra (international regimes and organizations) levels of government (Jessop 2002). For example, while decentralization often intends to allow for better decision-making at the local level, it also constrains the state's ability to regulate and distribute resources that are critical to facilitate adaptation (Eakin and Lemos, 2006). The West African pastoral Peulhs or Fulbes who lost access to water and pastures in the hands of settled agricultural people who gained local power in the process of decentralization (Van Dijk *et al.* 2004) are a clear example. On the other hand, the design of participatory, integrated, and decentralized institutions such as in Brazil's recent water reform is likely to build adaptive capacity to climate change by improving availability and access to technology, involving stakeholders, and encouraging sustainable use (Lemos and Oliveira 2004). The social, political and institutional context within which new governance paradigms take place influences whether they support or constrain adaptive capacity.

Equity is an important dimension in the development of adaptation strategies (Adger *et al.*, 2005; Adger, Huq, and Mace, 2005). Adaptive capacity is highly uneven across human societies. Adaptation practices by natural-resource-reliant communities may benefit some parts of the community more than others (Murton 1999). Even within countries with seemingly high capacities to adapt (based on aggregate national indicators for GDP, education levels and technology), there are likely to be some regions and groups that face barriers and constraints to adaptation (O'Brien *et al.* 2006).

Rural communities in Africa and Latin America have developed the capacity to adapt and build a key element of resilience: the diversification of their livelihood strategies (Thomas and Twyman 2005). Rural settlements can cope with a seasonal downturn in rainfall or a mid-season drought by moving livestock, harvesting water, shifting crop mixes, and migration (Scoones *et al.* 1996). Of course, without occasional high rainfall periods, longer-term livelihood sustainability is severely compromised. Measures focussed on reducing poverty and increasing access to resources (e.g. mangrove planting to reduce the vulnerability of coastal communities in Vietnam), may enhance the resilience of affected communities or economic activities. Policy focusing on adaptation has the potential to create positive synergies between outcomes (better managed natural and social systems) and processes (governance that promotes democratic decision making, participatory management strategies, equity, transparency, and accountability), which in turn will yield more resilient systems.

The kinds of social and economic effects described above also suggest cultural impacts: (i.e., on patterns of behaviour, including ideas, beliefs, customs, and codes) especially in traditional cultures where livelihoods are deeply imbedded in tradition. An indication of what could be ahead for other traditional cultures is the current experience of indigenous groups in the Arctic such as the Inuit (Fenge 2001; Kruse *et al.* 2004; ACIA 2004).

Adapting government services to changed needs associated with climate change – as with climate variation – is generally facilitated by effective leadership and structures for participative decision-making, where potentially affected parties are involved in assessing alternative responses. The most difficult challenges are where decision-makers lack access to information about climate change implications and possible responses, where fiscal limitations limit local flexibility, and where institutional capacities for coping with <u>any</u> major challenge, whether related to climate change or not, are inadequate.

7.6.6 Key adaptation issues

The central issues for adaptation to climate change by industry, settlements, and society are 1) impact types and magnitudes and their associated adaptation requirements, 2) potential contributions by adaptation strategies to reducing stresses and impacts, 3) costs of adaptation strategies relative to benefits, and 4) limits of adaptation in reducing stresses and impacts under realistically conceivable sets of policy and investment conditions (Downing 2003). Underlying all of these issues, of course, is the larger issue of the adaptive *capacity* of a population, a community, or an organization: the degree to which it can (or is likely to) act – through individual agency or collective policies – to reduce stresses and increase coping capacities (Chapter 17). In many cases, this capacity differs significantly between developing and developed countries.

In industries, communities, and societies at large, the most common approach is likely to be decentralized and autonomous, using information to make adjustments appropriate to each context and in many cases cooperating with others facing similar challenges. If such "autonomous" approaches are unlikely to be adequate in keeping impacts within a bearable range, the knowledge base on disaster response suggests that a number of other approaches may be helpful in enhancing and facilitating adaptive behaviour: systems to provide advance warning of changes, especially extreme events; institutional structures that facilitate collective action and provide external linkages; economic systems that offer access to alternatives; increased attention to adaptive structures that are locally appropriate, geographically and/or sectorally; contingency planning and risk financing, which may include strategic stockpiles; incorporating climate change vulnerability into land use planning for the long term; and in some cases physical facility investment, such as flood walls, beach restoration, or emergency shelters.

More specifically:

1 Prospects for adaptation depend on the magnitude and rate of climate change: adaptation is more feasible when climate change is moderate and gradual than when it is massive and/or abrupt. However, actual adaptation strategies and measures are often triggered by relatively extreme weather events (VERY HIGH CONFIDENCE).

2 Climate change adaptation strategies are inseparable from increasingly strong and complex global linkages. Industrial planning, human settlements, and social development are not isolated from changes in other systems or scales. The urban and rural are interconnected, as are developed and developing societies. This issue is becoming more salient as the globalized economy becomes more interdependent. Adaptation decisions for local activities owned or controlled by external systems involve different processes from adaptation decisions for local activities that are under

local control (VERY HIGH CONFIDENCE).

3 Adaptation depends fundamentally on such linkages, which shape potentials for human action. For instance, adaptation decisions for local activities owned or controlled by external systems involve distinctly different processes from adaptation decisions for local activities that are under local control (VERY HIGH CONFIDENCE).

4 Climate change is one of many challenges to human institutions to manage risks. In any society, institutions have developed risk management mechanisms for such purposes, from family and community self-help to insurance and re-insurance. It is not clear whether, where, and to what degree existing risk management structures are adequate for climate change; but these institutions have considerable potential to be foundations for a number of kinds of adaptations (HIGH CONFIDENCE).

5 The relatively long time horizon of climate change and its impacts makes the potential for technological change a critical issue in evaluating adaptation prospects. Anticipated vulnerabilities and possible impacts in the mid to long range can in many cases be addressed, at least in part, by research and development. Targeting R&D on critical needs can add significantly to adaptability; on the other hand, failing to do so can leave gaps in coping capacities that are difficult to fill through institutional and policy response (HIGH CONFIDENCE).

6 Adaptation is not necessarily optimal. For example, recent stakeholder evaluations of scenarios of extreme sea level risk in three regions of Europe showed a variety of responses, including cases where entirely plausible public actions resulted in increasing net social and economic impacts rather than reducing them (Lonsdale *et al.* 2005); Poumadere *et al.* 2005; and Olsthoorn 2005).

7 Adaptation actions can be effective in achieving their goals and targets, but may have more other effects. These might be unintended consequences (e.g., increased flood risk downstream), reducing support for mitigation (e.g., higher energy demand with air conditioning), or reducing resources available to address vulnerabilities elsewhere (e.g., budget constraints affecting other development goals). The benefits of adaptation may not be delayed or not realized at all, for example when design standards are raised to protect against a storm of a certain magnitude that does not occur for another fifty years if then (MEDIUM CONFIDENCE).

7.7 Conclusions: implications for sustainable development

Sustainable development is largely about people, their well-being, and equity in their relationships with each other, in a context where nature-society imbalances can threaten economic and social stability. Because climate change, its drivers, its impacts, and its policy responses will interact with economic production and services, human settlements, and human societies, climate change is likely to be a significant factor in the sustainable development of many areas (e.g., Downing 2002). Simply stated, climate change has the potential to affect many aspects of human development, positively or negatively, depending on the geographic location, the economic sector, and the level of economic and social development already attained (e.g., regarding particular vulnerabilities of the poor, see Dow and Wilbanks 2003). Moreover, because settlements and industry are often focal points for both mitigation and adaptation, these aspects of nature-society interactions are likely to be at the heart of many kinds of development-oriented responses to concerns about climate change.

In most cases, with the Arctic being a notable exception (ACIA 2004), these connections between climate change and sustainable development will only begin to emerge in the next decade or two (e.g., during the period embraced by the Millennium Development Goals) as a result of significant impacts that can be attributed to climate change. But industry, settlements, and societies will be important aspects of mitigation actions and adaptations involving land uses and capital investments with relatively long lifetimes.

The most serious sustainable development issues associated with climate change impacts on the subjects of this chapter are: 1) threats to vulnerable regions and localities from ecological changes and extreme events that could disrupt the sustainability of societies and cultures, with particular attention to coastal areas in current storm tracks and to economies and societies in polar areas, dry land areas, and low-lying islands, and 2) prospects of low-probability but high-consequence abrupt climate changes that would exceed the coping capacities of affected sectors, locations, and societies. Examples include effects on resource supply for urban and industrial growth and waste management (e.g., flooding). As a very general rule, sensitivities of more developed economies to the implications of climate change are less than in less developed economies; but effects of crossing thresholds of sustainability could be especially large in "brittle" industrialized economies: i.e., economies whose foundations are both rigid and frail.

In general, however, climate change is an issue for sustainable development mainly as *one of many* sources of possible stress (e.g., Wilbanks 2003c; O'Brien and Leichenko 2000 and 2003). Its significance lies primarily in its interactions with stresses and stress-related thresholds of a variety of other kinds, such as population growth and redistribution, social and political instability, and poverty and inequity. In the longer run, climate change is likely to affect sustainable development by reshaping the world map of comparative advantage which, in a globalizing economy, will support sustainable development in some areas but endanger it in others, especially in areas with limited capacities to adapt. Underlying such questions, of course, are the magnitude and pace of climate change. Most human activities and societies can adapt given information, time, and resources, which suggests that actions which moderate the rate of climate change are likely to reduce negative effects of climate change on sustainable development (Wilbanks 2003c).

At the same time, development paths may increase or decrease vulnerabilities to climate change impacts. For instance, development that intensifies land use in areas vulnerable to extreme weather events or sea level rise adds to risks of climate change impacts. Another example is development that moves an economy and society toward specialization in a single economic activity if that activity is climate-sensitive; development that is more diversified is likely to be less risky. In many cases, actions that increase resilience of industry, settlements, and society to climate change will also contribute to development with or without climate change by reducing vulnerabilities to climate variation and increasing capacities to cope with other stresses and uncertainties (Wilbanks 2003c).

Impacts of climate change on development paths also include impacts of climate change response policies, which can affect a wide range of development-related choices, from energy sources and costs to industrial competitiveness to patterns of tourism. Areas and sectors most heavily dependent on fossil fuels are especially likely to be affected economically, often calling for adaptation strategies that may in some cases require assistance with capacity building, technological development, and transition financing.

7.8 Key uncertainties and research priorities

Because research on vulnerabilities and adaptation potentials of human systems has lagged behind research on physical environmental systems, ecological impacts, and mitigation, uncertainties dominate the subject matter of this chapter. Key issues include 1) uncertainties about climate change impacts at a relatively fine-grained geographic and sectoral scale, both harmful and beneficial, which undermine efforts to assess potential benefits from investments in adaptation; 2) improved understanding of indirect second and third order impacts: i.e., the trickle down of primary effects, such as temperature or precipitation change, storm behaviour change, and sea level rise, through interrelationships among human systems; 3) relationships between specific effects in one location and the well-being of other locations, through linkages in inflows/outflows and interregional trade and migration flows; 4) uncertainties about potentials, costs, and limits of adaptation in keeping stressful impacts within acceptable limits, especially in developing countries and regions (see Parson *et al.* 2003); and 5) uncertainties about possible trends in societal, economic, and technological change with or without climate change. A particular challenge is improving the capacity to provide more quantitative estimates of impacts and adaptation potentials under the sets of assumptions included in SRES and other climate change scenarios and scenarios of greenhouse gas emission stabilization, especially for time horizons of interest to decision-makers, such as 2020, 2050, and 2080.

All of these issues are very high priorities for research in both developed and developing countries, with certain differences in emphasis related to the different development contexts. As a broad generalization, the primary impact issue for developed countries is the possibility of abrupt climate change, which could cause changes too rapid and disruptive even for a relatively developed country to absorb, at least over a period of several decades. High priorities include reducing uncertainty about the potential for adaptation to cope with climate change impacts in the absence of abrupt climate change and considering possible responses to threats from low-probability/high consequence contingencies. The primary impact issue for developing countries is the possibility that climate change, combined with other stresses affecting sustainable development, could jeopardize livelihoods and societies in many regions. High priorities include improving the understanding of multiple-stress contexts for sustainable development and improving the understanding of climate-sensitive thresholds for components of sustainable development paths.

Some of these uncertainties call for careful location and sector-specific research, emphasizing especially vulnerable areas such as coastal areas in lower-income developing countries and especially vulnerable sectors such as tourism. Others call for attention to cross-sectoral and multi-locational relationships between climate change adaptation and mitigation (Chapter 18), including both complementarities and tradeoffs in policy and investment strategies. Underlying all of these issues for industry, settlement, and society are relationships between possible climate change impact vulnerabilities and adaptation responses and broader processes of sustainable economic and social development, which suggest a need for a much greater emphasis on research that investigates such linkages. In some cases, because of the necessarily speculative nature of research about future contingencies, it is likely to be useful to consider past experiences with climate variability and analogs drawn from other experiences with environmental changes and stresses (e.g., Association of American Geographers 2003).

Underlying all of these research needs are often painfully serious limitations on available data to support valid analysis, especially data on nature-society linkages and data on relatively detailed-scale contexts in both developed and developing countries (e.g., Wilbanks *et al.* 2003a). If information about possible impacts, vulnerabilities, and adaptation potentials for industry, settlement, and society is to be substantially improved, serious attention is needed to establishing improved data sources on human-environmental relationships in both developing and developed countries, improving the integration of physical and earth science data from space-based and in-situ observation systems with socioeconomic data, and improving the ability to associate data systems with high-priority questions.

References

Abels, H. and T. Bullens, 2005: *Microinsurance*, Microinsurance Association of the Netherlands. (MIAN) [global, insurance]

Abrar, C.R. and S. N. Azad, 2004: *Coping with displacement: Riverbank erosion in north-west Bangladesh.* University Press Ltd, Dhaka [Asia, settlements].

ACIA 2004: *Arctic Climate Impact Assessment, Policy Document*, Fourth Arctic Council Ministerial Meeting, Reykjavík, 8 pp. [Arctic, social issues].

Adger, W. N., N. W. Arnell, and E. L. Tompkins, 2005. Successful Adaptation to Climate Change Across Scales, *Global Environmental Change*, 15, *in press* [global, adaptation].

Adger W.N., S. Huq, M. J. Mece, and J. Paavola, (eds.), 2005: *Equity and Justice in Adaptation to Climate Change*, MIT Press, Cambridge, [global, adaptation].

Adger, W. N., N. W. Arnell, and E. L. Tompkins, 2005: Successful adaptation to climate change across scales, *Global Environmental Change* (15), (in press), [global, adaptation].

Agnew M.D. and J. P. Palutikof, 1999: The impacts of climate on retailing in the UK with particular reference to the anomalously hot summer of 1995. *International Journal of Climatology* 19: 1493-1507 [Europe, service].

Agnew, M. and D. Viner, 2001: Potential impact of climate change on international tourism. *Tourism and Hospitality Research*, 3, 37-60 [global, tourism].

Ahern M, R. S. Kovats, P. Wilkinson, R. Few, and F. Matthies, 2005: Global health impacts of floods: epidemiologic evidence. *Epidemiologic Reviews* 27:36-46 [global, health].

Akbari, H., S. Bretz, D.M. Kurn and J. Hanford, 1997: Peak power and cooling energy savings of high-albedo roofs. *Energy & Buildings*, 25(2): 117-126. [global, energy].

Allen, M. 2005: The spectre of liability: Part 1 – Attribution, Part 2 – Implications In: [K. Tang (ed)]. *The Finance of Climate Change, Risk Books*, London, pp. 367-380 and 381-400 [global, insurance].

Andrey, J. and B. Mills, 2003: Climate change and the Canadian transportation system: vulnerabilities and adaptations. In: *Weather and Transportation in Canada*, [Andrey, J. and C. Klapper, (eds.)]. Department of Geography, University of Waterloo: Waterloo, CN, pp 235-279. [North America, transportation]

Anon. 2004: Government of Canada and Canadian pulp and paper industry agree on blueprint for climate change action, *Forest Chronicle*, 80(1): 9-9. [North America, industry]

Arsenault, R., 1984: The end of the long hot summer: The air conditioner and southern culture, *The Journal of Southern History*. 50, 597-628. [North America, settlements]

Assis, E. S. and A. B. Frota, 1999: Urban bioclimatic design strategies for a tropical city. *Atmospheric Environment*, 33, 4133-4142. [Latin America, settlements]

Association of American Geographers, 2003: *Global change in local places: estimating, understanding, and reducing greenhouse gases*, [GCLP Research Team: Kates, R., T. Wilbanks, and R. Abler (eds.)]. Association of American Geographers, Cambridge University Press, Cambridge, MA. [North America, scale]

Association of British Insurers, 2002: *Renewing the partnership: How the insurance industry will work with others to improve protection against floods*, London: 10 pp. [Europe; insurance]

Ausubel, J. and H. D. Langford, (eds.), 1997: *Technological Trajectories and the Human Environment*. Washington, DC: National Academy of Sciences. [global, adaptation]

Baker, L. A., A. J. Brazel, N. Selover, N. McIntyre, F. R. Steiner, A. Nelson, and L. Musacchio, 2002: Urbanization and warming of Phoenix, (Arizona, USA): impacts, feedbacks and mitigation. *Urban Ecosystem*, 6, 183-203. [North America, settlements]

Becken, S., C. Frampton, and D. Simmons, 2001: Energy consumption patterns in the accommodation sector – the New Zealand case. *Ecological Economics* 39, 371–386. [Australia/New Zealand, energy].

Becken, S., 2005: Harmonizing climate change adaptation and mitigation: The case of tourist resorts in Fiji, *Global Environmental Change*, 15(4), 381-393 [global tourism].
Belle, N. and B. Bramwell, 2005: Climate change and small island tourism: Policymaker and industry perspectives in Barbados," *Journal Of Travel Research* 44(1), 32-41.[island nations, tourism]
Benson, C. and E. Clay, 2003. Disasters, vulnerability and the global economy, in A. Kreimer, M. Arnold, and A. Carlin, *Building Safer Cites: The Future of Disaster Risk*, Disaster Risk Management Series No. 3: Washington, DC: World Bank [global settlements].
Berkhout, F., J. Hertin, and D. Gann, 2005: Learning to adapt: Organizational adaptation to climate change impacts, *Climatic Change*, (in press) [global, industry]
Besancenot, J. P., 1989: *Climat et tourisme*. Masson, Paris, 223 pp., [global tourism]
Bigio, A., 2003: "Cities and Climate Change," In: *Building Safer Cities. The Future of Disaster Risk*, [Kreimer A., M. Arnold, and A. Karlin, (eds.)] World Bank, [global, settlements]
Black, R., 2001: *Environmental Refugees: Myth Or Reality? New Issues in Refugee Research* Working Paper 34, United Nations High Commissioner for Refugees, Geneva, [global, social issues]
Breslow, P. and D. Sailor, 2002: Vulnerability of wind power resources to climate change in the continental United States, *Renewable Energy*, 27: 585–598 [North America, energy]
Brewer, T., 2005: U.S. public opinion on climate change issues: implications for consensus building and policymakers, *Climate Policy*, 4(4): 359-376 [North America, adaptation].
Broadmeadow, T., D. Ray, and C. Samuel, 2005: Climate change and the future for broadleaved forests in the UK, *Forestry*, 78(2), 145-161 [Europe, industry].
Bulkeley, H., and M.M. Betsill, 2003: *Cities and Climate Change: Urban Sustainability and Global Environmental Governance*. Routledge, New York [global settlements].
Cairncross, S. and M.J.C. Alvarinho, 2005: The Mozambique floods of 2000: health impact and response. In: *Flooding and Health*, [R. Few, (ed.)], Earthscan, London, (in press) [Africa, infrastructure]
Cannon, T., 2002: Gender and climate hazards in Bangladesh, *Gender and Development*. 10, 45-50 [Asia, social issues]
Capeluto, I. G., A. Yezioro, and E. Shaviv, 2003: Climate aspects in urban design-a case study. *Building and Environment.* 38, 827-835 [global, settlements]
Ceron, J. P., 2000: Tourisme et changement climatique. In: *Impacts potentiels du changement climatique en France au XXIème siècle*. Premier ministre, Ministère de l'aménagement du territoire et de l'environnement, 1998, deuxième édition 2000, pp. 104-111 [Europe, tourism]
Ceron, J. and G. Dubois, 2005: The potential impacts of climate change on French tourism, *Current Issues in Tourism*, 8(2-3), 125-139 [Europe, tourism].
Christie, F. and J. Hanlon, 2001: *Mozambique and the Great Flood of 2000.* James Currey for the International African Institute, Oxford, 176 pp. [Africa, infrastructure].
Clark, W. C., *et al*., 2000: *Assessing Vulnerability to Global Environmental Risks*. Discussion Paper 200-12, Environment and Natural Resources Program, Kennedy School of Government, Harvard University, Cambridge, MA [global, vulnerability]
Consodine, T. J., 2000: The impacts of weather variations on energy demand and carbon emissions, *Resource and Energy Economics*, 22: 295-314 [global, energy]
Cross, J., 2001: Megacities and small towns: Different perspectives on hazard vulnerability. *Environmental Hazards*, 3, 63-80 [global, settlements].
Dinar, A., M.W. Rosegrant, and R. Meinzen-Dick, 1997: *Water allocation mechanisms: principles and examples*. Policy Research Working Paper WPS 1779, World Bank, Washington, DC, 41 pp [global, infrastructure].
Dow, K. and T. Wilbanks, 2003: Poverty and Vulnerabilities to Climate Change. *Briefing Note.* Adaptation Research Workshop, New Delhi, November 2003 [global, sustainable development]
Downing, T.E., 2002: Linking sustainable livelihoods and global climate change in vulnerable food systems. *die Erde* 133, 363-378 [global, social issues]

Downing, T.E., 2003: Lessons from famine early warning systems and food security for understanding adaptation to climate change: Toward a vulnerability adaptation science? In: [Smith, J.B., R.J.T. Klein, and S. Huq, (eds.)], *Climate Change, Adaptive Capacity and Development*. Imperial College Press, London, pp. 71-100 [global, adaptation]
Dubois, G. and J. P. Ceron, 2005: Changes in leisure/tourism mobility patterns facing the stake of global warming: the case of France, *Belgeo*, 1-2, 103-121 [Europe, tourism]
Dyson, B., 2005: Throwing off the shackles: 2004 insurance performance rankings, *Reactions*, [global, insurance]
Eakin, H. and M. C. Lemos, 2006: Adaptation and expectations of nation-state action: the challenge of capacity-building under globalization, *Global Environmental Change* (in press) [global, social issues]
Easterling, W. E., *et al.*, 2004: *Coping With Global Climate Change: The Role Of Adaptation In The United States*, Pew Center on Global Climate Change, Arlington VA, 40 pp. [North America, adaptation]
Eddowes, M.J., *et al.*, 2003: *Safety Implications of Weather, Climate and Climate Change*, Report AEAT/RAIR/76148/R03/005 Issue 2, AEA Technology, Warrington, [Europe, transportation]
Elsasser, H. and R. Burki, 2002: Climate change as a threat to tourism in the Alps, *Climate Research*, 20, 253-257 [Europe, tourism]
Emanuel, K., 2005: Increasing destructiveness of tropical cyclones over the past 30 years, *Nature*, 434, 686-688 [global, insurance]
Environment Agency, 2004: *Maintaining Water Supply*, London, England, 74 pp. [Europe, infrastructure]
Environment Canada, 1997: *The Canada Country Study: Climate Impacts and Adaptation.* Adaptation and Impacts Research Group, Downsview, Ontario, [North America, adaptation]
Enz, R., 2000: The S-curve relation between per-capita income and insurance penetration, *The Geneva Papers*, 25(3), 396-406 [global, insurance]
European Environment Agency, 2004: *Impacts Of Europe´s Changing Climate*. European Environment Agency Report No 2/2004, ISBN: 92-9167-692-6, Copenhagen, 100 pp. [Europe, impacts]
Fairhead, J., 2004: Achieving sustainability in Africa. In: *Targeting Development. Critical Perspectives on the Millennium Goals*, [Black, R. and H. White, (eds)], London, Routledge: 292-306 [Africa, sustainable development].
Feng, T., 2001: The Inuit and climate change, *Canadian Journal of Policy Research,* 2/4, [North America, social issues]
Feng, H., L. Yu, and W. Solecki,)eds), 2006: *Urban Dimensions of Environmental Change – Science, Exposure, Policies, and Technologies*, Science Press, Monmouth Junction, NJ, [global, settlements].
Few, R., M. Ahern, F. Matthies, and S. Kovats, 2004: Floods, health and climate change; a strategic review. Tyndall Centre for Climate Change Research, Working Paper No. 63. Norwich, UK, [global, infrastructure].
Folland, C. K., *et al.*, 2001: Projections of future climate change. In: IPCC, 2001, op. cit. [global, assumptions]
Fowler, H.J., *et al.*, 2005: New estimates of future changes in extreme rainfall across the UK using regional climate model integrations. 1. Assessment of control climate. *Journal of Hydrology*, 300, 212-233 [Europe, assumptions]
Freeman, P. and W. Koko, 2001: *Vulnerability of Infrastructure to Climate Variability. How Does This Affect Infrastructure Lending Policies*?, Washington, DC, The World Bank [global, insurance]
Fukushima, T., M. Kureha, N. Ozaki, Y. Fukimori, and H. Harasawa, 2003: Influences of air temperature change on leisure industries: Case study on ski activities. *Mitigation And Adaptation Strategies For Climate Change* 7(2): 173-189 [global, tourism].
Furevik, T., H. Drange and A. Sorteberg. 2002: *Anticipated Changes In The Nordic Seas Marine Climate*, Fisken og havet,. Institute for Marine Research's Scientific Report Series, 4, 1-13 [Europe, infrastructure]

Gallopin, G., A. Hammond, P. Raskin, and R. Swart, 1997: *Branch Points Global Scenarios and Human Choice*, SEI, [global, assumptions]

Gomez, F., L. Gil, and J. Jabaloyes, 2004: Experimental investigation on the thermal comfort in the city: relationship with the green areas, interaction with the urban microclimate. *Building and Environment,* 39, 1077-1086 [global, settlements]

Gössling, S. and C. M. Hall, 2005: An introduction to tourism and global environmental change. In: *Tourism and Global Environmental Change. Ecological, Social, Economic and Political Interrelationships.* [Gössling, S. and C. M. Hall, (eds)], London: Routledge, [global, tourism]

Graves, H. M. and M. C. Philipson, 2000: *Potential Implications Of Climate Change In The Built Environment*. FBE Report 2. Foundation for the Built Environment, London, [global, settlements]

Gurenko, E., 2004: Building effective catastrophe insurance programs at the country level: a risk management perspective. In: *Catastrophe Risk and Reinsurance: A Country Wide Risk Management Perspective,* Risk Books, London, pp. 4 [global, insurance]

Hadley, S. W., D. J. Erickson III, J. L. Hernandez, and S. L. Thompson, 2004: *Future U.S. Energy Use for 2000-2025 as Computed with Temperatures from a Global Climate Prediction Model and Energy Demand Model*. Oak Ridge National Laboratory, Lawrence Livermore National Laboratory, 10 pp. [North America, energy]

Hamilton, J.D. Maddison, and R. Tol, 2005: "Climate change and international tourism. A simulation study." Global environmental change 15(3): 253-266 [global, tourism]

Hamilton, L., D. Rohall, B. Brown, B, G. Hayward, and B. Keim, 2003: Warming winters and New Hampshire's lost ski areas: an integrated case study. *International Journal Of Sociology And Social Policy*, 23(10), 52-68 [North America, tourism]

Harman, J., M. Gawith, and M. Calley, 2005: Progress on assessing climate impacts through the UK Climate Impacts Programme, *Weather* 60, 258-262 [Europe, impacts]

Hartwig R., 2006: *Hurricane Season Of 2005, Impacts On US P/C Markets, 2006 And Beyond,* Presentation to the Insurance Information Institute, New York, NY. Accessed on 17.04.2006 at http://www.iii.org/media/presentations/katrina/ [North America, insurance].

Hertin, J., F. Berkhout, D. M Gann, *et al.* 2003: Climate change and the UK house building sector: perceptions, impacts and adaptive capacity, *Building Research And Information* 31 (3-4): 278-290 [Europe, industry].

Hitz, S. and J. Smith, 2000: Estimating global impacts from climate change, *Global Environmental Change* 14, 201–218 [global, costs].

Holman, I.P., M. Rounsevell, S. Shackley, P. Harrison, R. Nichols, P. Berry, and E. Audsley, 2005: A regional, multi-sectoral and integrated assessment of the impacts of climate and socio-economic change in the UK, Part I, Methodology, Part II, Results, *Climatic Change*, 71 [Europe, costs]

Hunter, J.R., 2006: Testimony of J. Robert Hunter, Director of Insurance, Consumer Federation of America, before the Committee on Banking Housing and Urban Affairs of the United States Senate, regarding proposals to reform the National Flood Insurance Program,. Accessed 14.04.2006 at http://banking.senate.gov/_files/ACF4AC9.pdf [North America, insurance]

Hough, M. (2004): *Cities and Natural Processes: A Basis for Sustainability*, 3d ed., London: Routledge [global, settlements]

IPCC, 2001a: Human settlements, energy, and industry. In: IPCC 2001b: [global, TAR]

IPCC, 2001b: *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. Cambridge University Press, Cambridge, 967 pp, [global, TAR]

IPCC, 2001c: Insurance and other financial services. In: IPCC 2001b [global, TAR]

IPET Post-Katrina/Interagency Performance Evaluation Taskforce, March 2006: *Performance Evaluation Report 2 and Interim Status*. Accessed 17.04.2006 at https://ipet.wes.army.mil/ [North America, vulnerabilities]

ISDR/EIRD, *Living With Risk. A Global Review Of Disaster Reduction Initiatives, 2004 version,* Inter-Agency Secretariat of the International Strategy for Disaster Reduction (UN/ISDR), Geneva [global, insurance]

Jessop, B. 2002: *Globalization and the National State In Paradigm Lost: State Theory Reconsidered*, University of Minnesota Press, [Aronowitz, S. and P. Bratsis, (eds.)], Minneapolis, MN:, pp. 185-220 [global, social issues]

Jollands, N., M. Ruth, C. Bernier, N. Golubiewski, R. Andrew, and V. Forgie, 2005: *Climate's Long-term Impacts on New Zealand Infrastructure, Phase 1 Report, Hamilton City Case Study*. New Zealand Centre for Ecological Economics, Palmerston North, New Zealand [Australia/New Zealand, infrastructuress].

Jones, B., Scott, D., 2006: Implications of climate change to Ontario's provincial parks, *Leisure*, (in press) [North America, tourism]

Jones, B., D. Scott, and H. Abi Khaled, H., 2006: Implications of climate change for outdoor event planning: A case study of three special events in Canada's National Capital region." *Event Management* (in press) [North America, tourism]

Kainuma M., Y. Matsuoka, T. Morita, T. Masui, and K. Takahashi, (2004): Analysis of global warming stabilization scenarios: the Asian-Pacific Integrated Model. *Energy Economics*, 26, 709–719 [global, energy]

Kates, R. and T. Wilbanks, 2003: Making the global local: responding to climate change concerns from the bottom up. *Environment*, 45/3, 12-23 [global, scale]

Kershow, P. J. and B. Messon, 2005: *Lessons learned between hurricanes: From Hugo to Charley, Frances, Ivan and Jeanne* – In: Summary of the March 8, 2005 Workshop of the Disasters Roundtable, The National Academies, 28 pp. [North America, vulnerabilities]

Kiernan, M., 2005: Climate Change, Investment Risk, and Fudiciary Responsibility. In: [The Finance of Climate Change Risk Books, (K. Tang, ed.)], pp 211-226 [global, insurance].

Kinney, P.L., J.E. Rosenthal, C. Rosenzweig, C. Hogrefe, W. Solecki, K. Knowlton, C. Small, B. Lynn, K. Civerolo, J.Y. Ku, R. Goldberg, and C. Oliveri. 2006: Assessing the Potential Public Health Impacts of Changing Climate and Land Use: The New York Climate & Health Project. In: *Climate Change and Variability: Consequences and Responses* [Ruth M., K. Donaghy P. Kirshen, (eds.)], U.S. Environmental Protection Agency, Washington, D.C. (in press) [North America, settlements]

Kirshen, P. H., 2002: Potential impacts of global warming in eastern Massachusetts. *Journal of Water Resources Planning and Management*, ASCE 128 (3): 216-226 [North America, settlements]

Kirshen, P.H., M.R. Ruth, and W. Anderson, 2006: Interdependencies of urban climate change impacts and adaptation strategies: a case study of metropolitan Boston USA., *Climatic Change* (in press) [[North America, settlements]

Kirshen, P., M. Ruth, and W. Anderson, 2006: *Climate's Long-Term Impacts On Urban Infrastructures And Services: The Case Of Metro Boston.* In: Chapter 7, Climate Change and Variability: Local Impacts and Responses, [Ruth, M., K. Donaghy, and P.H. Kirshen, (eds.)], Edward Elgar Publishers, Cheltenham, England (in press) [[North America, settlements]

Klein, R. *et al.*, 1998: Resilience and vulnerability: Coastal dynamics or Dutch dikes? *Geographical Journal*, 164, 259-268 [Europe, costs]

Klein, R.J., T.J. Nicholls, and J. Thomalla, 2003: *The Resilience Of Coastal Mega Cities To Whether Related Hazards In Building Safer Cities: The Future Of Climate Change*, [Kreimer A., M. Arnold, and A. Karlin (eds.)], World Bank, Washington DC, pp. 101-121 [global, settlements]

Klinenberg, E., 2002: *Heat Wave: A Social Autopsy of Disaster in Chicago*. The University of Chicago Press, Chicago [North America, settlements].

Knowlton, K., J., E. Rosenthal, C. Hogrefe, B. Lynn, S. Gaffin, R. Goldberg, C. Rosenzweig, K. Civerolo, J.-Y. Ku, and P. L. Kinney. 2004: Assessing ozone-related health impacts under a changing climate, *Environmental Health Perspectives* 112: 1557-1563 [global, settlements].

Kont, A., J. Jaagus, and R. Aunap, 2003: Climate change scenarios and the effect of sea-level rise for Estonia. *Global and Planetary Change*, 36, 1-15 [Europe, costs].

Kruse, J., *et al.*, 2004. Modeling sustainability of arctic communities, *Ecosystems*. 7: 815-28 [Arctic, social issues]

Kuik, O., 2003: Climate change policies, energy security and carbon dependency: Trade-offs for the European Union in the longer term, International Environmental Agreements: *Politics, Law and Economics* 3: 221–242 [Europe, energy]
Lagadec, P., 2004. Understanding the French 2003 heat wave experience, *Journal of Contingencies and Crisis Management*. 12/4: 160-69 [Europe, settlements].
Lancaster, J.W., M. Preene, and C. T. Marshall, 2004: *Development and Flood Risk: Guidance for the Construction Industry,* Report CR037A, CIRIA, London, 180 pp. [Europe, industry].
Lemos, M. C. and J. L. F. Oliveira, 2004: Can water reform survive politics? Institutional change and river basin management in Ceará, Northeast Brazil. *World Development*, 32, 2121-2137 [Latin America, social issues].
Lewsey, C., G. Cid, and E. Kruse, 2004: Assessing climate change impacts on coastal infrastructure in the Eastern Caribbean, *Marine Policy*, 28, 393-409 [Caribbean, infrastructure].
Lin, C.W.R. and H.Y.S. Chen, 2003: Dynamic allocation of uncertain supply for the perishable commodity supply chain, *International Journal of Production Research*, 41(13), 3119-3138 [global, services].
Lindsey G., 1999: Use of urban greenways: insights from Indianapolis. *Landscape and Urban Planning*, 45, 145-147. [North America, settlements].
Linnerooth, B.J., R. Mechler, and G. Pflug, 2005: Refocusing disaster aid, *Science*, 309, pp. 1044-1046 [global, insurance]
Liso, K. R., G. Aandahl, S. Eriksen *et al.*, 2003: Preparing for climate change impacts in Norway's built environment, *Building Research And Information* 31 (3-4): 200-209 [Europe, settlements].
London Climate Change Partnership, 2004: *London's Warming, A Climate Change Impacts in London Evaluation Study*, London, 293 pp. [Europe, settlements].
London, J.B., 2004: Implications of climate change on small island developing states: Experience in the Caribbean region, *Journal of Environmental Management and Planning,* 47(4), 491-501 [Caribbean, tourism].
Lonsdale, K., T.E. Downing, R.J. Nicholls, D. Parker, A.T. Vafeidis, R. Dawson and J.W. Hall, 2005: Plausible Responses To The Threat Of Rapid Sea-Level Rise For The Thames Estuary, FNU-77, Hamburg University and Centre for Marine and Atmospheric Science, Hamburg [Europe, costs]
Maddison, D., 2001: In search of warmer climates? The impact of climate change on flows of British tourists. *Climatic Change*, 49, 193-208 [Europe, tourism].
Maier, H. R. *et al.*, 2001: First-order reliability method for estimating reliability, vulnerability, and resilience, *Water Resources Research*, 37, 779-790 [global, vulnerabilities].
Marris, E., 2005: "First Tests Show Flood Waters High in Bacteria and Lead," *Nature*, on-line news, 14 September 2005: doi:10.1038/437301a [North America, impacts]
Martin, B., 2005: Weather, climate and tourism: A geographical perspective, *Annals of Tourism Research*, 32(3), 571-591 [global, tourism].
Matzarakis, A., C. R. de Freitas, (eds.), 2001: *Proceedings of the 1st International Workshop on Climate, Tourism and Recreation*, International Society of Biometeorology, Commission on Climate Tourism and Recreation [global, tourism].
Matzarakis, A., C.R. de Freitas, D. Scott, (eds.), 2004: *Advances In Tourism Climatology*. Berichte des Meteorologischen Institutes der Universität Freiburg N° 12 [global, tourism].
McGranahan, G., 2002: *Demand-Side Water Strategies and the Urban Poor*. International Institute for Environment and Development, London, 70 pp. [global, infrastructure].
McKenzie, K. and K. Parlee, 2003: The Road Ahead – Adapting to Climate Change in Atlantic Canada, *Elements*, [North America, adaptation].
Mendelsohn, R., (ed.), 2001: *Global Warming and the American Economy*, Edward Elgar Publisher, Aldershot, UK. [North America, costs].
Mills, B. and J. Andrey, 2002: *Climate Change and Transportation: Potential Interactions and Impacts*. In: USDOT Summary and Discussion Papers of a Workshop on The Potential Impacts of

Climate Change on Transportation, October 1-2, 2002, in Washington, DC. [North America, transportation].

Mitchell, R. and P. Romero Lankao, 2004: Institutions, science and technology in a transition to sustainability. In: *Earth System Analysis for Sustainability* [Schellnhuber, H.-J., P. J. Crutzen, W. C. Clark, and M. Claussen (eds.)]. MIT, Cambridge, [global, sustainable development].

Molina, M. *et al.*, 2005: *Air Quality in the Mexico Megacity: An Integrated Assessment*, Kluwer, Dordrecht, Netherlands [Latin America, settlements].

Montgomery, M. R., R. Stren, B. Cohen, and H. E. Reed, 2004: *Cities Transformed. Demographic Change and its Implications in the Developing World*. Earthscan, UK [global, settlements]

Mortimore, M.J., 1989: Adapting To Drought: Farmers, Famines, and Desertification In West Africa, Cambridge, UK: Cambridge University Press, 219 pp. [Africa, adaptation]

Munich Re., 2005: *Weather Catastrophes And Climate Change, Is There Still Hope For Us? Munich,* 264 pp, [global, insurance]

Murton, J., (1999): Population growth and poverty in Machakos District, Kenya, *Geographical Journal*, 165: 37-46 [Africa, adaptation]

National Research Council 2002: *Abrupt Climate Change: Inevitable Surprises*, Washington, National Academies Press [global, costs].

NACC, 2000: *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*. U.S. Global Change Research Program, Washington, DC, 154 pp. [North America, impacts]

Nelson, F.E., O.A. Anisimov, and N. I. Shiklomanov. 2001: Subsidence risk from thawing permafrost, *Nature*, 410, 889-890 [Arctic, industry].

Nicholls, R. J., 2004: Coastal flooding and wetland loss in the 21st century: changes under the SRES climate and socio-economic scenarios, *Global Environmental Change*, 14, 69-86 [global, costs].

Nicholls, R., and R. Tol, 2006: Impacts and responses to sea-evel rise: A global analysis of the SRES scenarios over the 21st century," *Philosophical Transactions of the Royal Society A*, (in press) [global, costs].

O'Brien, K. and R. M. Leichenko, 2000: Double exposure: assessing the impact of climate change within the context of economic globalization, *Global Environmental Change*, 10, 221-232 [global, assumptions]

O'Brien, K. L. and R.M. Leichenko, 2003: Winners and losers in the context of global change. *Annals of the Association of American Geographers*, 93, 89-103 [global, assusmptions].

O'Brien, K., L. Sygna, and J. E. Haugen, 2004a: Vulnerable or resilient? a multi-scale assessment of climate impacts and vulnerability in Norway, *Climatic Change*, 62(1-3), 75-113 [Europe, services].

O'Brien, K.L., H.L. Tompkins, S. Eriksen, and P. Prestrud, P. 2004b: *Climate Vulnerability in the Barents Sea Ecoregion: A Multi-Stressor Approach*, CICERO Report 2004:07. Centre for International Climate and Environmental Research, Oslo, 34 pp. [Europe, vulnerabilities]

O'Brien, K.L., S. Eriksen, L. Sygna, and L.O. Næss, 2006: Questioning complacency: Climate change impacts, vulnerability and adaptation in Norway. *Ambio*. (in press) [Europe, vulnerabilities].

Ocampo, J. A. and J. Martin (eds.) 2003: *A Decade of Light and Shadow. Latin America and the Caribbean in the 1990s*, LC/G.2205-P/I [Latin America, current conditions].

O'Connell, M. and R. Hargreaves, 2004: *Climate Change Adaptation: Guidance on Adapting New Zealand's Built Environment for the Impacts of Climate Change*, BRANZ Ltd, Porirua, New Zealand [Australia/New Zealand, adaptation].

OECD, 2004: *OECD Territorial Reviews: Mexico City*, OECD, Paris, 148 pp. [global, costs].

Office of City Auditor, Seattle, 2005: *Climate Change Will Impact the Seattle (USA) Department of Transportation*. City of Seattle, USA [North America, settlements].

Oke, T. R., 1982: The energetic basis of the urban heat island, *Quarterly Journal*, Royal Meteorological Society, 108, 1-24 [global, energy].

Olsthoorn, A.A., P.E. van der Werff, L.M. Bouwer and D. Huitema, 2005: *Neo-Atlantis: Dutch Responses to Five Meter Sea Level Rise*, FNU-75, Hamburg University and Centre for Marine and

Atmospheric Science, Hamburg [Europe, costs].
ORNL/CUSAT 2003: *Possible Vulnerabilities of Cochin, India to Climate Change Impacts and Response Strategies to Increase Resilience*, Oak Ridge National Laboratory and Cochin University of Science and Technology, July 2003.
Oxley, A., 2002: *The WTO Doha Development Round*, APEC Study Center, Monash University Australia [global, services]
PAHO, 1988: *Natural Disaster Mitigation in Drinking Water and Sewerage Systems: Guidelines for Vulnerability Analysis*, Pan-american Health Organization, Washington, D.C. [global, infrastructures]
PAME. 2000: *Snap Shot Analysis of Maritime Activities in the Arctic*. Norwegian Maritime Directorate. Report [Arctic, transportation].
Parkinson, J. and O. Mark, 2005: *Urban Storm water Management in Developing Countries*, London: IOA, 240 pp. [global, infrastructures].
Parry. M. L. (ed,) 2000: *Assessment of Potential Effects and Adaptations for Climate Change in Europe*. Jackson Environmental Institute, UEA, Norwich, UK., 320 pp. [Europe, impacts]
Parson, E. A., *et al.*, 2003: Understanding climatic impacts, vulnerabilities, and adaptation in the United States: Building a capacity for assessment, *Climatic Change*, 57, 9-42 [North America, research].
Peeters, P., 2003: *The Tourist, the Trip and the Earth*. In: NHTV Marketing and Communication Departments, ed. *Creating a Fascinating World*. Breda, NHTV, pp. 1-18 [global, tourism]
Pelletier, J.V., V. Letard, H. Flandre, S. Lepeltier, 2003: *Rapport D'information Fait Au Nom De La Mission: "La France Et Les Français Face á La Canicule: Les Lecons D'une Crise*" Report to the Sénat, Goverment of France [Europe, settlements].
Pielke R.A. C. Landsea M. Mayfield, J. Lavel and R. Pasch R (2005): Hurricanes and global warming, *American Meteorological Society*, 1571-1575 [global, assumptions].
Pinho, O. and M.. Orgaz, 2000: The urban heat island in a small city in coastal Portugal, *International Journal of Biometeorology*, 44: 198-200 [Europe, energy].
Poumadère, M., C. Mays, G. Pfeifle with A.T. Vafeidis, 2005: *Worst Case Scenario and Stakeholder Group Decision: A 5-6 Meter Sea Level Rise in the Rhone Delta, France*, FNU-76, Hamburg University and Centre for Marine and Atmospheric Science, Hamburg [Europe, costs].
ProVention Consortium, 2004: Experiences in Micro-Insurance. In: Report on ProVention Consortium International Workshop, October 22, 2004, Zurich [global, insurance].
Rees, W., 1992: Ecological footprints and appropriated carrying capacity: What urban economics leaves out, *Environment and Urbanization*, 4, 121-130 [global, settlements].
Renewable Energy Centre (REC), 2004: *Strategies for Reducing the Vulnerability of Energy Systems to Natural Disasters in the Caribbean*, Barbados Renewable Energy Centre. Bridgetown, Barbados [Caribbean, energy].
Rhode, T. E., 1999: Integrating urban and agriculture water management in southern Morocco. *Arid Lands News Letter 45*, [Africa, infrastructures]
Romero-Lankao, P. *et al.*, 2005: *Can Cities Reduce Global Warming? Urban Development and Carbon Cycle in Latin America*, IAI/UAM-X/IHDP/GCP, Mexico City, 92pp. [Latin America, settlements].
Romero Lankao, 2006: ¿Hacia una gestión sustentable del agua? Alcances y límites de la descentralización hidráulica en la ciudad de México? In: *La Gestión del Agua Urbana en México*, [Barkin, D. (ed.)], UdeG/UAM Xochimilco, México, [Latin America, settlements].
Rose, A., and G. Oladosu, 2002: Greenhouse gas reduction in the U.S.: Identifying winners and losers in an expanded permit trading system, *Energy Journal*, 23, 1-18 [North America, impacts]
Rose, A., and Z. Zhang, 2004: Interregional burden-sharing of greenhouse gas mitigation in the United States, *Mitigation and Adaptation Strategies for Global Change*, 9, 477-500 [North America, impacts].
Rosenzweig, C., and W. D. Solecki, 2001a. *Climate Change and a Global City: The Metropolitan East Coast Regional Assessment*. Columbia Earth Institute, New York, 24 pp. [North America, settlements]

Rosenzweig, C. and W.D. Solecki, 2001b: Global environmental change and a global city: Lessons for New York, *Environment.* 43(3): 8-18 [North America, settlements],
Rosenzweig, C., W. D. Solecki, L. Parshall, M. Chopping, G. Pope, and R. Goldberg, 2005: Characterizing the urban heat island in current and future climates in New Jersey, *Global Environmental Change,* 6(1): 51-62 [North America, settlements]
Ruosteenoja, K., T. R. Carter, K. Jylhä, and H. Tuomenvirta, 2003: *Future Climate In World Regions: An Intercomparison Of Model-Based Projections For The New IPCC Emissions Scenarios,* Finnish Environment Institute, Helsinki, 83 pp. [global, assumptions].
Ruth, M., B. Davidsdottir, and A. Amato, 2004: Climate change policies and capital vintage effects: the case of U.S. pulp and paper, iron and steel, and ethylene, *Journal of Environmental Management*, 70, 235-252 [North America, industry].
Ruth M., K. Donaghy and P. Kirshen, (eds .), 2006: *Climate Change and Variability: Consequences and Responses*. Washington, D.C.: U.S. Environmental Protection Agency [North America, impacts].
Salagnac, J. L., 2004: French perspective on emerging climate change issues, *Building Research And Information* 32(1): 67-70 [Europe, industry].
Sanchez-Rodriguez, R., K.C. Seto, D. Simon, W.D. Solecki, F. Kraas, and G. Laumann, 2005: *Science Plan: Urbanization and Global Environmental Change,* International Human Dimensions Programme of Global Environmental Change, Bonn, Germany [global, settlements].
Sanders, C.H. and M.C. Phillipson, 2003: UK adaptation strategy and technical measures: The impacts of climate change on buildings, *Building Research and Information*, 31(3-4), 210-221 [Europe, settlements].
Sasidharan, V., C. Yarnal, B. Yarnal, and G. Godbey, 2001: Climate change: What does it mean for parks and recreation management?, *Parks and Recreation*, 54-60 [global, tourism].
Scoones, I., with C. Chibudu, S. Chikura, P. Jeranyama, D. Machaka, W. Machanja, B. Mavedzenge, B. Mombeshora, M. Mudhara, C. Mudziwo, F. Murimbarimba and B. Zirereza, 1996: *Hazards and Opportunities. Farming Livelihoods in Dryland Africa: Lessons from Zimbabwe*. Zed Books, London, [Africa, social issues].
Scott, D., B. Jones, *et al.*, 2005: *Climate, Tourism and Recreation: a Bibliography -1936 to 2005*, University of Waterloo, Waterloo, Canada [global, tourism].
Shashua-Bar, L., M. and E. Hoffman, 2000: Vegetation as a climatic component in the design of an urban street, an empirical model for predicting the cooling effect of urban green areas with trees, *Energy and Buildings*, 31, 221-235 [global, energy].
Shashua-Bar, L., M. E. Hoffman, 2002: The Green CTTC model for predicting the air temperature in small urban wooded sites. *Building and Environment*, 37, 1279-1288 [global, energy].
Shashua-Bar, L., M. E. Hoffman, 2004: Quantitative evaluation of passive cooling of the UCL microclimate in hot regions in summer, case study: urban streets and courtyards with trees. *Building and Environment*, 39, 1087-1099 [global, energy].
Shepherd, J.M., H. Pierce and A.J. Negri. 2002: Rainfall modification by major urban areas: Observatons from spaceborne rain radar on the TRMM satellite, *J. of Applied Meteorology*, 41, 689-701 [global, energy]
Shiklomanov, I. A., 2000: Appraisal and assessment of world water resources. *Water International*, 25, 11-32 [global, infrastructure]
Shimoda, Y. , 2003: Adaptation measures for climate change and the urban heat island in Japan's built environment, *Building Research And Information* 31(3-4): 222-230 [Asia, energy].
Shukla, P.R., M. Kapshe and A. Garg, 2004: *Development and Climate: Impacts and Adaptation for Infrastructure Assets in India*. Presentatiotn at the OECD Global Forum on Sustainable Development: Development and Climate Change, Paris [Asia, energy].
Solecki, W. D., and C. Rosenzweig: 2006: Climate change and the city: Observations from metropolitan New York. In: *Cities and Environmental Change*, [Bai, Xuemei (ed.)], Yale University Press, New York, (in press) [North America, settlements].

Spence, R., A. Brown, and P. Cooper, 2004: Whether to Strengthen? Risk analysis for Strengthening decision-making, In: *Proceedings of Henderson Colloquium 2004: Designing for the Consequence of Hazards*, International Association for Bridge and Structural Engineers, Cambridge, Paper 12 [global, insurance].
Subak, S. *et al.*, 2000: The impact of the anomalous weather of 1995 on the U.K. economy, *Climatic Change*, 44, 1-26 [Europe, impacts].
Swiss Re, 2004: *Tackling Climate Change.* Focus report, Zurich, 10 pp. [global, insurance].
Taha, H. 1996: Modeling the impacts of increased urban vegetation on ozone air quality in the south coast air basin, *Atmospheric Environment*, 30(20), 3423-3430 [North America. settlements]
Taha, H., S. Douglas, and J. Haney, 1997: Mesoscale meteorological and air quality impacts of increased urban albedo and vegetation, *Energy and Buildings*, 25(2), 169-177 [North America, settlements]
Tarr, J. A., 1996: *The Search for the Ultimate Sink: Urban Pollution in Historical Perspective*. University of Akron, Akron, OH, 419 pp. [global, settlements].
Thomas, D. S. C. and C. Twyman, 2005: Equity and justice in climate change adaptation among natural-resource dependent societies, *Global Environmental Change* 15 (in press) [global, social issues]
Tol, R. S. J., 2002a: Estimates of the damage costs of climate change, Part I: Benchmark estimates, *Environment and Resource Economics*, 21, 47-73 [global, costs]
Tol, R. S. J., 2002b: Estimates of the damage costs of climate change, Part II: Dynamic estimates, *Environment and Resource Economics*, 21, 135-160 [global, costs]
Tol, R., *et al.*, 2006: Adaptation to five metres of sea level rise, *Journal of Risk Research*, (in press) [global, costs]
Toth, F. and T. Wilbanks, 2004: *Considering the Technical and Socioeconomic Assumptions Embedded in the SRES Scenario Families*, IPCC Working Group II Guidance Papers, Fourth Assessment Report, IPCC Working Group II, Technical Support Unit, Exeter, UK, [global, assumptions]
Turner, B. L. II, *et al.*, 2003: *A Framework for Vulnerability Analysis in Sustainability Science*, Proceedings of the National Academy of Sciences, Washington, DC, July 8-14, 2003, 8074-8079 [global, vulnerabilities].
Twardosz R., 1996. La variabilité des précipitations atmosphériques en Europe Centrale pendant la période 1850-1995. Publications de l'Association Internationale de Climatologie, 9, p. 520-527. [Europe, settlements]
UK Climate Impacts Programme, 2002: *Briefing Note: Climate change impacts on buildings*, Oxford, United Kingdom, 4 pp. [Europe, industry]
UK Water Industry Research, 2004: *Climate Change and the Hydraulic Design of Sewerage Systems: Summary Report,* Report 03/CC/10/0, UKWIR, London, [Europe, infrastructures]
UN 2004: *UN Population Prospects: the 2004 Revision Population Database*. Accessed on 16.02.2006 at http://esa.un.org/unpp [global, assumptions]
United Nations Population Division, 2001: *World Urbanization Prospects*, NY: United Nations [global, assumptions].
UNCTAD, 2002: *Trade And Development Report, 2002*. UNCTAD, New York, 198 pp. [global, service].
United Nations *Environment Programme Finance Initiatives (UNEP FI), 2002*: CEO Briefing on Climate Change and the Financial Services Industry [global, costs]
Unruh, J., M.Krol, N. Kliot, 2004. *Environmental change and its implications for population migration*. Advances in Global Change Research, Vol. 20, Springer, [global, social issues]
Van Dijk, H., de Bruijn M., and van Beek W. 2004: Pathways to mitigate climate variability and climate change in Mali. In: A.J.Dietz, R. Ruben & A. Verhagen (eds). *The impact of climate change on drylands, with a focus on West Africa.* Dordrecht/Boston/London : Kluwer Academic Publishers, (465 pp.), pp. 173-206. [Africa, adaptation]
Vilcheck, G. E., 1998: Ecosystem health, landscape vulnerability, and environmental risk assessment,

Ecosystem Health, 4, 52-60 [global, vulnerabilities]
Vogel, R. M. *et al.*, 1999: Storage reservoir behavior in the United States, *Journal of Water Resources Planning and Management*, 125, 245-54 [North America, infrastructures]
WHO/Unicef, 2000: *Global Water Supply and Sanitation Assessment 2000 Report*. World Health Organization with Unicef, Geneva, 79 pp. [global, infrastructures]
WBGU 2006: *World in Transition - Fighting Poverty through Environmental Policy*. German Advisory Council on Global Change. London: Earthscan, 352 pp. [global, social issues]
Wilbanks, T. J. and R. Kates, 1999: Global change in local places, *Climatic Change*, 43/3, 601-628 [global, scale]
Wilbanks, T. J. and others, 2003a: Possible responses to global climate change: integrating mitigation and adaptation. *Environment*, 45/5, 28-38 [global, sustainable development]
Wilbanks, T. J., 2003b: Geographic scaling issues in integrated assessments of climate change. In: *Scaling Issues in Integrated Assessment* [Rotmans, J. and D. Rothman (eds.)]. Swets and Zeitlinger, pp. 5-34 [global, scale].
Wilbanks, T. J., 2003c: Integrating climate change and sustainable development in a place-based context. In: *Climate Policy*. Supplement on Climate Change and Sustainable Development, November 2003, pp. 147-154 [global, sustainable development]
Wilbanks, T. J. and others, 2005: Toward an Integrated Analysis of Mitigation and Adaptation: Some Preliminary Findings, in *Challenges in Integrating Mitigation and Adaptation as Responses to Climate Change*, special issue, *Mitigation and Adaptation Strategies for Global Change* (in press) [global,, sustainable develoment]
Willows, R. and R. Connell, 2003: *Climate Adaptation: Risk, Uncertainty and Decision-Making*, UKCIP Technical Report, Oxford, 154 pp. [Europe, adaptation]
Winchester, P., 2000: Cyclone mitigation, resource allocation and post-disaster reconstruction in South India: Lessons from two decades of research, *Disasters*, 23/4, 18-37 [Asia, adaptation].
Wolmer, W. and I. Scoones, I. (eds.), 2003: Livelihoods in crisis: new perspectives on governance and rural development in southern Africa, *IDS Bulletin* 34 (3) [Africa, social issues]
Woon, G. and D. Rose, 2004: Why the Whole Island Floods Now, *Nassau Guardian and Tribune*, Retrieved 25.07.2005 from http://www.unesco.org/csi/smis/siv/Caribbean/bahart3-nassau.htm. [Caribbean, impacts]
World Tourism Organization, 2003: Climate change and tourism. In: *Proceedings of the 1st International Conference on Climate Change and Tourism,* 9-11, April 2003, World Tourism Organization. Djerba, Tunisia. Madrid, Spain [global, tourism].
Wright, E.L. and J.D. Erickson, 2003: Climate variability, economic adaptation and investment timing, *Int. J. Global Env. Issues*, 3,4: 357-368 [global, adaptation].
Yohe, G., R.S.J. Tol., 2001: Indicators for social and economic coping capacity—moving toward a working definition of adaptive capacity. *Global Environmental Change* 12, 25–40 [global, adaptation].